CHAPTER 3

INTRODUCTION TO TELEPHONE SYSTEMS

31. Components of Telephone Systems

To provide satisfactory service, the telephone system must include, besides transmitters and receivers, components such as ringers, switchboards, and transmission lines. This chapter explains the over-all functions of these additional components and shows how they are used in a number of common telephone systems. Later chapters will present in detail the principles of their operation.

32. Simple Telephone Circuit

a. The simplest telephone circuit is obtained by connecting a transmitter to a receiver, as in figure 26. In such a circuit, the transmitter may be located a considerable distance from the receiver, perhaps several miles away, and yet a person speaking into the transmitter at station A can be heard by another person at the receiver at station B. One-way telephone communication is effected.

b. One-way communication serves for the transmission of intelligence in one direction, but it is inadequate for most of the purposes for which the telephone is used. Two-way conversation is indispensable. Figure 27 shows how simply this can be arranged. A receiver is added at the transmitting end and a transmitter at the receiving end. With two transmitters and two receivers, so connected, the voice of a person speaking into either transmitter can be heard in both receivers, and two-way communication is effected between stations A and B.

c. Although the circuit in figure 27 can be used as the basis for a simple telephone system, its usefulness is limited. How can a person at station A signal someone at station B to come to the phone so that conversation may begin? Although the circuit does not provide any means, this, too, is arranged simply (fig. 28). At each station, A and B, *signaling* (ringing) *circuits* are added, and these make it possible for a person at either station to signal the other station when conversation is desired. A signaling circuit includes a *ringer* (bell or buzzer) and a *hand generator*. A person at station A, wishing to talk with someone at station B, turns the crank of the hand generator. This generates an a-c voltage which sends a signaling current over the transmission line to operate the

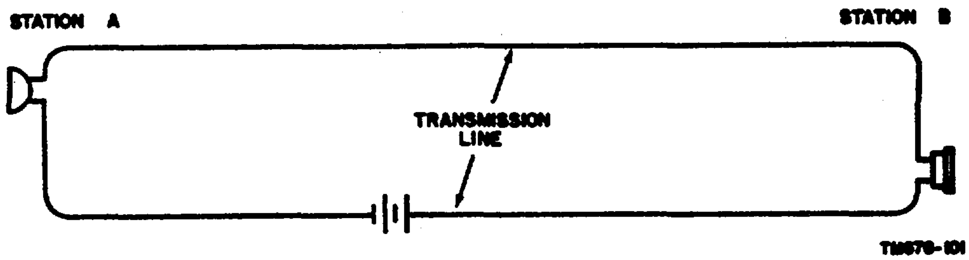


Figure 26. Simple telephone circuit.

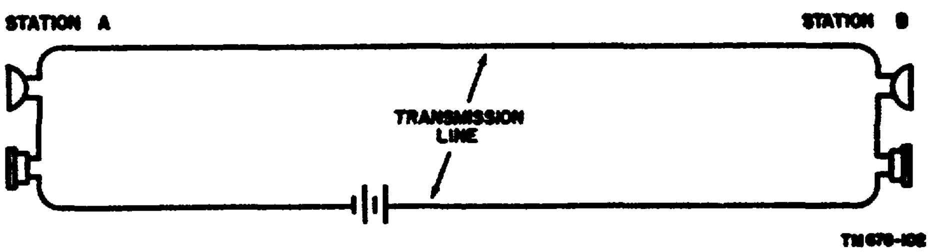


Figure 27. Practical telephone circuit.

CHAPTER 4

LOCAL-BATTERY TELEPHONY

41. Equipment of Local-Battery Telephone System

The equipment of the local-battery telephone system may be classified as telephone-station equipment, central-office equipment, and interconnecting equipment. The unit of equipment at the telephone station is the telephone set, and the unit of equipment at the central office is the switchboard. The interconnecting equipment is the telephone line. Because the electrical properties of the telephone line are, in general, similar for both the local-battery and the common-battery systems, discussion of the line will be deferred for a later chapter, following discussion of the common-battery system.

42. Telephone Set

In both systems, the *telephone set*, often simply called the *telephone*, is the device supplied the telephone user to initiate and receive telephone calls. In the telephone circuit of figure 28, the group of components at each station comprises a simple telephone set. The group includes the transmitter, the receiver, the hand generator, and the ringer.

a. Principal Circuits of Telephone Set. The components of the telephone set of both systems are connected to provide two principal circuits: the talking circuit in A, figure 40, and the signaling circuit, shown in B. Each one is the telephone circuit of figure 28 modified to represent two local-battery telephone sets connected directly to each other. The circuits of the telephone sets are completed by the telephone line connected to terminals L1 and L2 of the sets.

(1) The *talking circuit* of the telephone set provides an electrical path for the voice current. Its prime components are the transmitter and the receiver. In the local-battery telephone set, it also includes

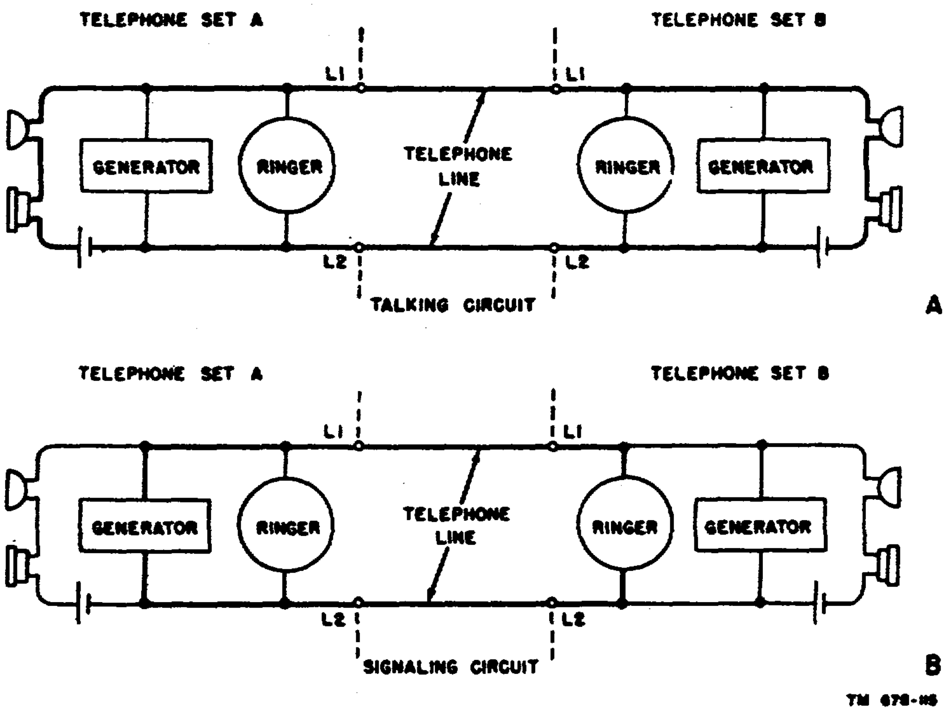


Figure 40. Circuits of local-battery telephone sets.

a battery. *In the two-station local-battery* system shown in A, the heavy lines show the complete talking circuit, which includes the transmitters, the receivers, the batteries of the two telephones, and the connecting telephone line. Thus, voice currents generated by a person speaking into the transmitter of one telephone have a complete electrical path through the telephone line to the receiver of the other telephone.

(2) The *signaling circuit* of the telephone set provides an electrical path through the signaling device for the signaling current. Its prime component is the ringer. In the local-battery telephone set it also includes a hand generator. In B, the heavy lines show the complete signaling circuit between the two telephones. It includes the generator of telephone set A, the ringer of telephone set B, and the connecting telephone line. Rotation of the

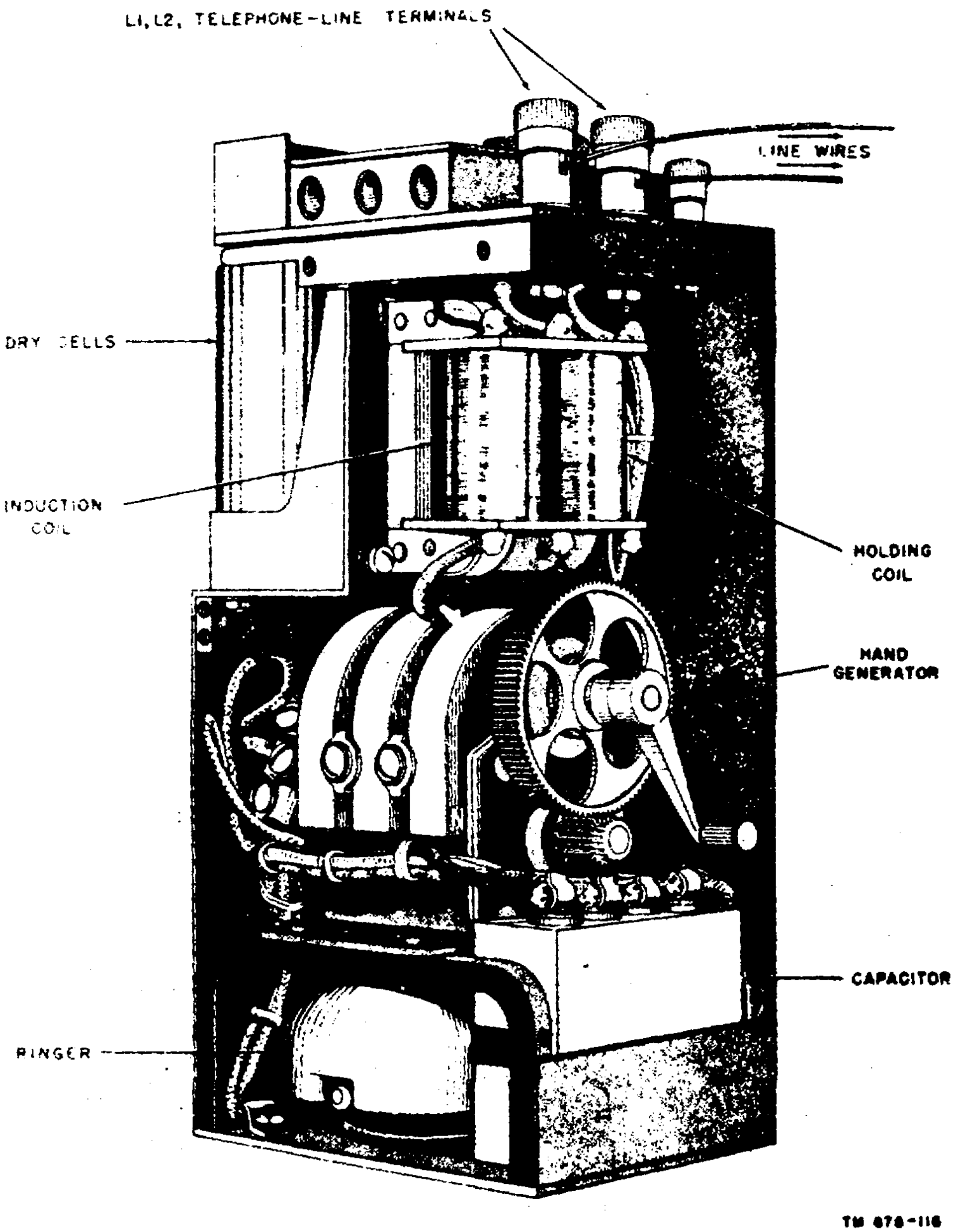


Figure 41. Local-battery telephone set, excluding handset.

crank of the hand generator of telephone A generates an alternating current which is conducted by the telephone line to the ringer of telephone B and causes it to operate. The switches referred to are not shown in the illustration. A similar circuit exists between the hand generator of telephone B and the ringer of telephone A.

b. Components of Telephone Set. The components of a local-battery telephone set, excluding the handset, are shown in figure 41. In addition to the hand generator, the battery, and the ringer, there are an induction coil and a capacitor to improve electrical efficiency and performance.

43. Battery

The function of the *battery* in the local-battery telephone set is to supply the current for the transmitter. The battery consists of two or three dry cells, which obtain their electrical energy from the chemical action of the materials of which the cell is composed. The chemical action during current flow produces an accumulation of gas bubbles around the positive electrode, which insulates the electrode and increases the internal resistance of the cell. This action of the cell is called *polarization*. The manganese dioxide contained in the dry cell neutralizes the polarization, but its action is slow, and a continuous drawing of current causes the emf of the cell to fall rapidly. If the cell is given a short rest, however, the depolarization reaction *catches up*, and the emf increases to nearly its original value. Dry cells therefore are suited particularly for intermittent use. The emf of a new dry cell is about 1.53 volts, and it decreases with age.

44. Handset Switch

a. Function. A handset switch is usually a normally open, momentary (spring-return) switch. When pushed, it connects the transmitter in the talking circuit. When released, the transmitter is out of the circuit, thus conserving the battery when the transmitter is not in use.

b. Push-To-Talk Handset Switch. A, figure 42, illustrates a handset switch of push-to-talk type, frequently used in local-battery telephone sets. It consists of an assembly, or *pile-up*, of flat, spring-metal conductors, separated by insulators, as in B. Welded to the ends of the conductors are contacts made of a special alloy which withstands arcing when the switch is opened and closed. The contacts are closed by rotation of the butterfly nut attached to the short shaft which passes through the plate. When the butterfly nut is released, the spring action of the conductors opens the contacts and restores the switch to its normal, or open, position. The push-to-talk handset switch usually is mounted in the telephone handset between the transmitter and receiver (fig. 42). So located, the telephone user can connect the battery readily when speaking and disconnect it when listening. Figure 43 shows another handset with a push-to-talk switch. When speaking, the switch is pressed downward instead of sideways. On this handset, the receiver unit has been

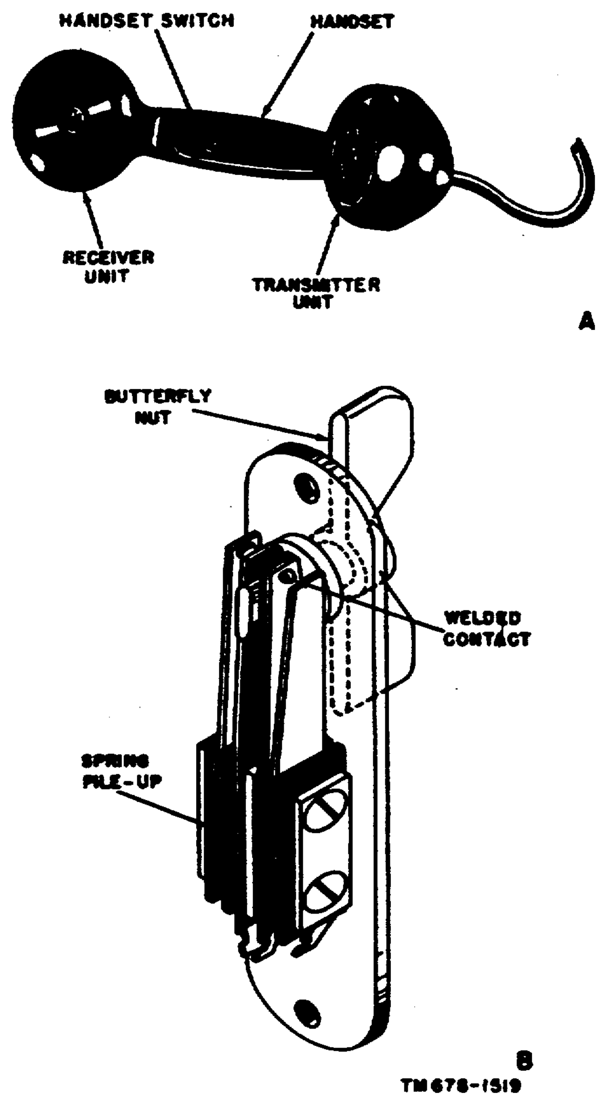


Figure 42. Handset with push-to-talk switch.

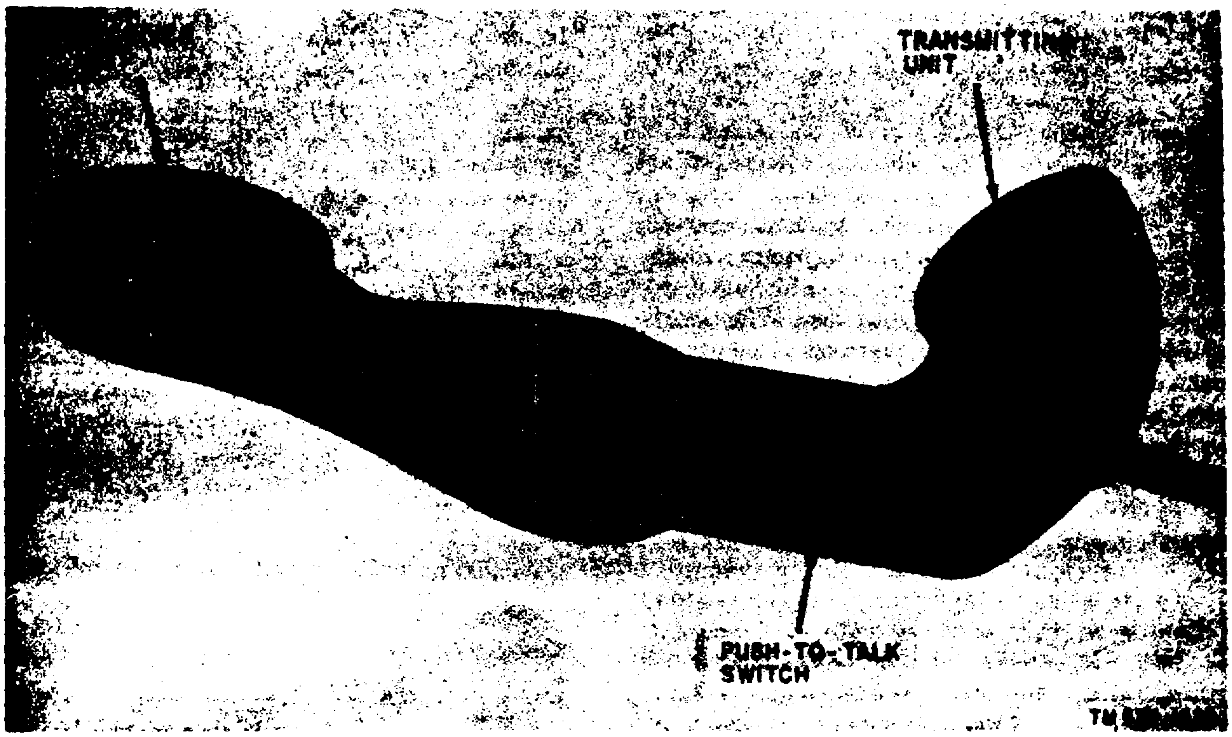


Figure 43. Military handset with push-to-talk switch.

made almost flat to allow the unit to be slipped under a helmet.

c. Circuit with Handset Switch.

(1) Figure 44 shows the talking circuit of two local-battery telephone sets, each of which includes a handset switch. It differs from the circuit of figure 40 in that the transmitters and receivers are in parallel instead of in series. This manner of connecting the components automatically results in a closed talking circuit between the two telephones when either handset switch is closed. This would not be the result if the components were connected in series with each of the transmitters; in the normal position, the spring-metal conductors hold the handset switch open, and the talking circuit would not be completed unless both handset switches were closed at the same time. In use, this could be managed, but it would require, between the persons speaking, a coordination that is unnecessary with the circuit of figure 44.

(2) The heavy lines (fig. 44) show the complete talking circuit between the two telephone sets: the transmitter, the battery, and the handset switch of telephone A and the receiver of telephone B. The handset switch of telephone A is shown

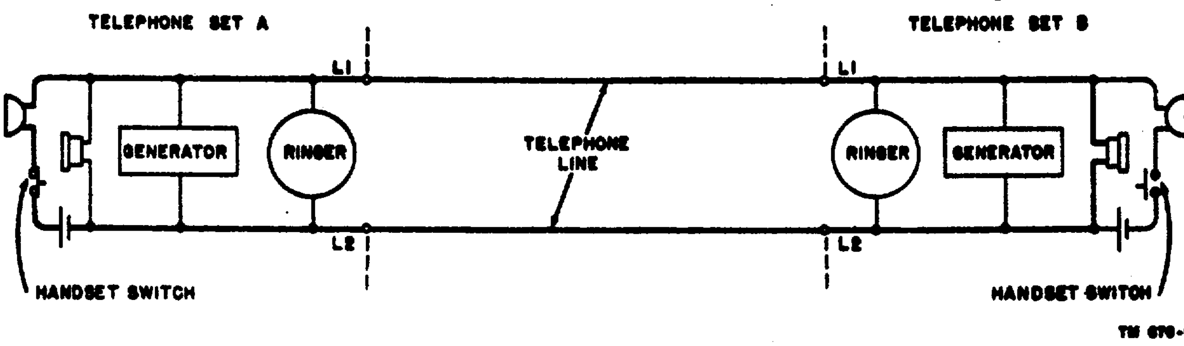


Figure 44. Talking circuit of two telephone sets with handset switches.

in the talking (closed) position, and that of telephone B is in the listening (open) position. (Telephone circuit diagrams usually show the switch in the open position.)

45. Handset

In most telephone sets, the transmitter and receiver units are contained in a single mounting, the *handpiece*, also called the *handle* and the *handset handle*. The combination of handpiece with transmitter, receiver, and connecting cord is called the *handset*. In the local-battery telephone set, the handset usually includes the push-to-talk handset switch. Figure 45 is an exploded view of the components of a local battery telephone handset.

a. Advantages of Handset. The handset provides a convenient support or mounting for the transmitter and receiver. In addition, its design results in an increase in the output of the transmitter. The transmitter is at the proper distance from the mouth of the telephone user when the receiver is against his ear; more of the sound energy of the speakers' voice is directed into the transmitter than might otherwise be the case, and the result is a greater average output of voice current.

b. Structure of Handset. The material of the handpiece is molded bakelite or a phenol plastic. Its ends are designed to contain the transmitter

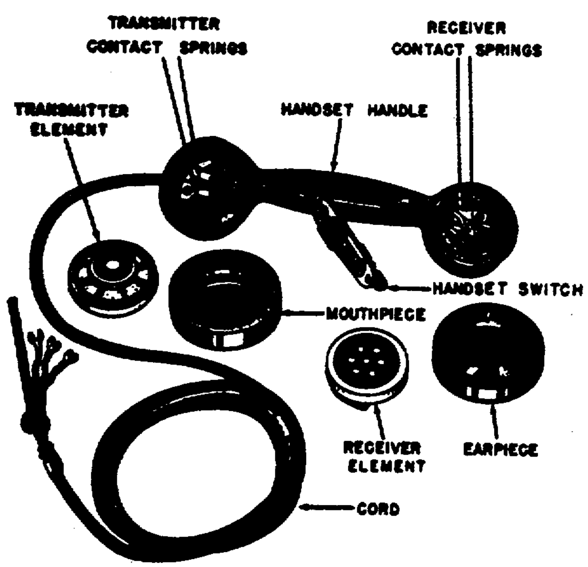


Figure 45. Exploded view of handset of local-battery telephone.

and receiver elements. These are retained by molded bakelite or phenolic plastic *caps*, perforated to pass the sound energy. The transmitter cap is called the *mouthpiece*, the receiver cap the *earpiece*. Connections to the transmitter and receiver are made by silver-plated contact springs, fastened to terminals molded in the plastic. In the local-battery telephone handset, the handle is recessed for mounting the push-to-talk switch in the handle. Metal tubes extending through this handle carry the necessary conducting wires between the transmitter, receiver, and handset switch.

c. Circuit of Handset. The broken lines of figure 46 show the wiring of the local-battery telephone handset. The receiver terminals and the handset switch are connected to terminals in the transmitter end of the handle. A three-conductor cord connects the handset to the telephone set. In

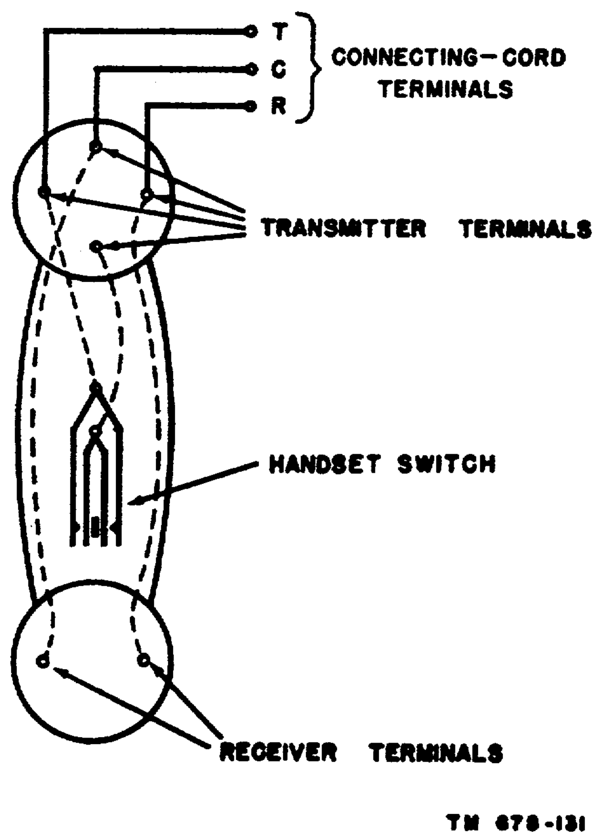


Figure 46. Wiring diagram of handset with handswitch.

practice, the individual conductors of the cord usually are identified by the color of the conductor leads; here (and in most circuit diagrams)

they are designated T for transmitter, C for common, and R for receiver.

46. Induction Coil

The circuits of the telephone sets of figures 40 and 44, using dry cells alone, can be used to provide voice conversation only between telephone sets separated by short distances. The range may be extended, however, and performance and efficiency may be improved, by including an *induction coil* in the circuit.

a. Functions. The induction coil performs two functions in this particular telephone set. First, it increases the voltage of the voice current generated by the transmitter. Second, it separates the transmitter and receiver currents so that the direct current of the transmitter circuit does not pass through the receiver (secondary) circuit.

b. Circuit. The circuit of a local-battery telephone set with an induction coil is shown in A and B, figure 47. The induction coil consists of two separate coils which have a common connection and are wound on an iron core. One coil, the *primary winding*, receives the electrical energy; the other, the *secondary winding*, delivers the electrical energy to the circuit. The induction coil separates the circuit of the telephone set into two circuits, the transmitting circuit and the receiving circuit.

(1) The *transmitting circuit* is emphasized by the heavy lines in A. This circuit includes the primary winding of the induction coil, the transmitter, the handset switch, and the battery, all in series. When the handset switch is closed, direct current from the battery is supplied only to the primary circuit.

(2) The *receiving circuit* is shown by the heavy lines in B. This circuit includes the secondary winding of the induction coil and the telephone receiver.

(3) The function of the transmitting and receiving circuits of the telephone set will be considered after the following discussion of the basic principles of the induction coil.

47. Principles of Induction Coil

a. Comparison with Transformer. The induction coil is essentially a *transformer*. This similarity may be noted by comparing the circuit diagrams of the transformer and induction coil in figure 48. Electrically, the action of an induction coil is the same as that of a transformer, and the same basic principles apply to it. The transformer in its simplest form consists of two conducting coils which have mutual inductance between them. The common connection between the windings of the induction coil does not affect the

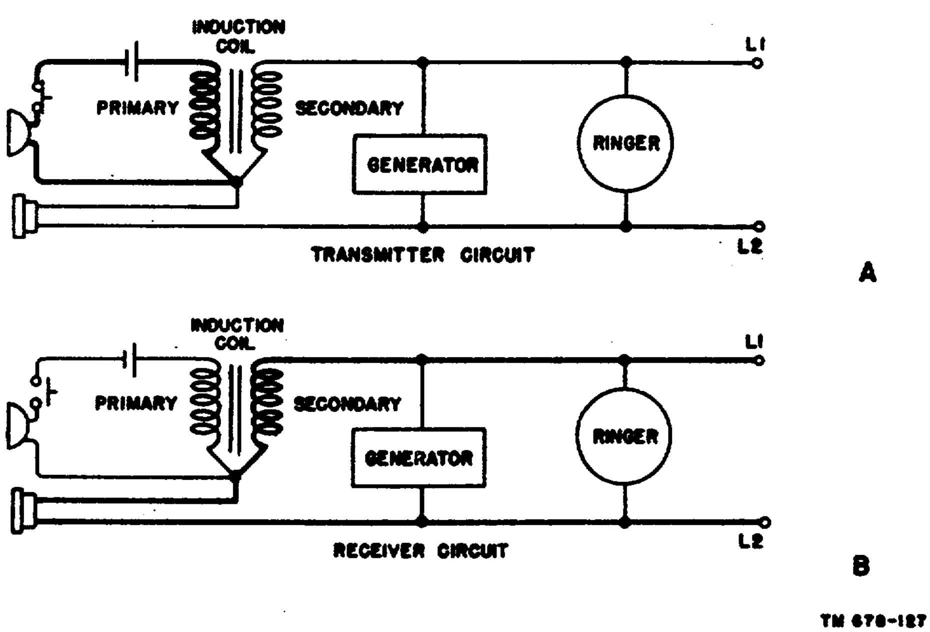


Figure 47. Local-battery telephone set with induction coil.

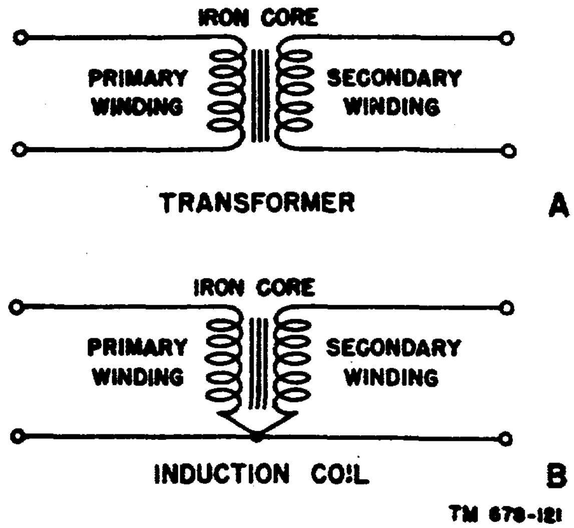


Figure 48. Comparison of transformer and induction coil.

mutual inductance between the coils. As a result of the mutual inductance, a varying current in one winding induces an a-c voltage in the other. The value of the induced a-c voltage depends on the turns ratio and on the rate at which the current changes: the higher the rate of change, the greater the induced voltage. The induced voltage has the waveshape of the changing current. This action of the transformer is explained in detail in TM 11–681.

b. Ideal Transformer. The properties of an *actual* transformer are understood more easily by considering the properties of an *ideal* transformer. An ideal transformer has no electrical losses. None of the electrical energy supplied to it is lost in the production of the magnetic field in the iron core, or lost as heat in the windings; and all the magnetic flux of the changing current in one winding links all the turns of the other winding. Physically this is not possible, of course, and no ideal transformer actually exists; but in performance the actual transformer approaches the ideal transformer so closely that the latter serves very well to explain its action.

(1) Figure 49 shows an *ideal* transformer with an a-c generator connected to its primary winding and a telephone receiver connected as a load to its secondary winding. A-c ammeters and voltmeters are connected as shown, to indicate the primary current, I_P, the primary voltage, E_P, the secondary current, I_S, and the secondary voltage, E_S.

(2) Consider the primary winding to have N_P turns and the secondary winding to have N_S turns. Since the ideal transformer has no electrical losses, all the power supplied to the primary winding is transferred to the secondary winding: The power input to the primary in watts, E_P times I_P, equals the power output of the secondary in watts, E_S times I_S. From this is obtained the relation,

$$\frac{E_S}{E_P}=\frac{I_P}{I_S}.$$

(3) Since all the magnetic flux of the primary winding links all the turns of the secondary winding, the ampere-turns of the primary, I_P times N_P, equal the ampere-turns of the secondary, I_S times N_S. From this is obtained the relation,

$$\frac{I_P}{I_S}=\frac{N_S}{N_P}.$$

(4) Since the ratio of secondary to primary voltage equals the ratio of primary to secondary current (fig. 49), and the ratio of secondary to primary turns equals the same ratio of primary to secondary current, the ratio of secondary to primary voltage also must equal the ratio of secondary to primary turns; or,

$$\frac{E_S}{E_P}=\frac{N_S}{N_P}, \text{ or } E_S=E_P\,\frac{N_S}{N_P}.$$

In other words, the secondary voltage equals the primary voltage times the ratio of the secondary turns to the primary turns. If this ratio is greater than one (if the secondary has more turns than

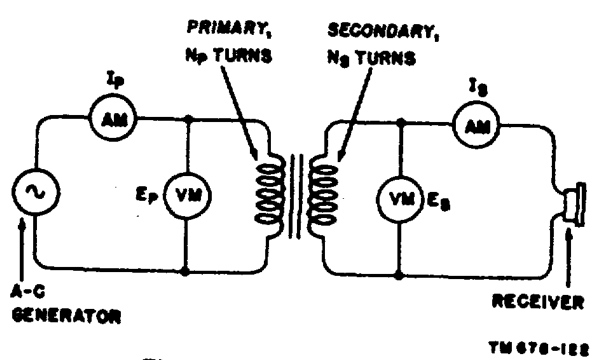


Figure 49. Ideal transformer.

the primary), the transformer is said to *step up* the voltage. If the ratio is less than one, the transformer is said to *step down* the voltage. In many telephone applications, the transformers have ratios equal to one (the primary and secondary have the same number of turns). The primary and secondary voltages of these transformers are the same, and they are used to isolate or separate physically one electrical circuit from another.

c. Actual Transformer. In an *actual* transformer, electrical losses do occur. They include losses caused by the resistance of the winding and the energy taken to provide the magnetic field in the iron core. Also, not all the magnetic flux of the primary winding links all the turns of the secondary winding. In actual transformers such as the induction coil, these losses are very small, however, and can be ignored. The action of the induction coil therefore is very similar to that of the ideal transformer.

48. Induction Coil in Telephone Set

a. Function of Circuit with Induction Coil. Figure 50 shows a circuit of two local-battery telephone sets with *induction coils.* To understand the function of the circuit in providing voice conversation between the two telephones, assume that a person at telephone A is about to speak to a person at telephone B.

(1) Before speaking into the transmitter, the person at telephone A closes the handset switch (fig. 50). This action completes the transmitter circuit, and battery current is supplied to the transmitter through the primary winding of the induction coil. The battery current remains constant; therefore no voltage is induced in the secondary winding of the induction coil, and there is no current in the secondary winding.

(2) This condition changes when the person at telephone A speaks into the transmitter (fig. 50). The sound waves of his speech produce a changing voice current in the transmitter circuit. The changing current induces an a-c (voice-current) voltage in the secondary winding of the same waveform as that of the changing current. As a result of the induced a-c voltage, a current is produced in the closed circuit consisting of the telephone line, the secondary windings, and the receivers of both telephones. The person at telephone B hears in his receiver a reproduction of the original speech sounds. The circuit functions in the same manner for transmission in the opposite direction.

(3) Both receivers are in the voice-current circuit during transmission from either end (fig. 50). Therefore, a person speaking into either transmitter hears his own voice in the receiver at his ear. This sound, reproduced in the receiver of the speaker, is called *sidetone.* The sidetone effect can be reduced by means of an *antisidetone circuit* using an antisidetone induction coil or an autotransformer (par. 59).

b. Common Connection of Induction Coil. The common connection between the primary and secondary windings of the induction coil does not affect its transformer action. The circuit in figure 50 would function just as well if the two windings were separate, as in a transformer. However, the common connection simplifies the circuit for the handset, by permitting reduction of the number of handset *cord conductors* from four to three (fig. 51). The common connection also is used for special circuits such as the antisidetone circuit, and

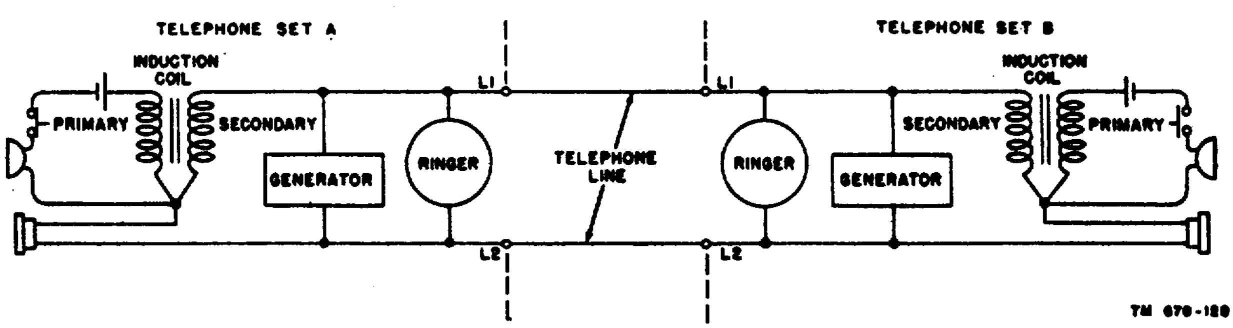


Figure 50. Circuit of two local-battery telephones with induction coil.

that of the common-battery telephone set to be discussed in the next chapter.

c. Effect of Direct Current in Winding of Induction Coil. The circuit in figure 50 prevents the direct current for the transmitter from passing through the receiver. This is desirable, because telephone receivers are not designed to operate with direct current in the receiver-coil winding. The effect on the receiver of direct current in the winding depends on the direction of the current; the direction can be such as to produce a magnetic flux which will either strengthen or weaken the field of the permanent magnet of the receiver. If the direction of the d-c magnetic flux is such that it *aids* the field of the permanent magnet, the pull on the diaphragm of the receiver *increases*. This usually makes the receiver more sensitive in its response to the voice current; but it also may bring the diaphragm into contact with the pole pieces, so that it is prevented from vibrating properly; or the diaphragm even may become clamped to the pole pieces. If the direction of the d-c magnetic flux is such that it *opposes* the field of the permanent magnet, the pull on the diaphragm of the receiver *decreases*. This usually makes the receiver less sensitive to the voice current and lowers its efficiency. Where permanent-magnet receivers are required to operate with direct current in the winding, the practice is to connect them so that the pull of the magnet is *strengthened* by the direct current. This is called *poling the receiver*. The induction coil does away with the necessity of poling the receiver of the local-battery telephone set.

d. Percent Change in Resistance Caused by Induction Coil. The induction coil in figure 50 increases in two ways the voltage of the voice current generated by the transmitter: First, it acts as a step-up transformer (since the secondary winding has more turns than the primary), and, second, it causes a greater *percent change* in the resistance of the transmitter circuit.

(1) To understand the effect of the induction coil in increasing the percent change in the resistance of the transmitter circuit, compare the circuits in A and B, figure 52. In both, the generators and ringers are omitted, since their resistance is relatively much greater than that of the other components. In A, the transmitter of telephone A is in series with all the other circuit components: both receivers, both batteries, the telephone line, and the other transmitter. In B, the transmitter of telephone A is in series only with the battery and primary winding of the induction coil. Now, the primary of the induction coil of the latter circuit has a much lower resistance than the total resistance of the components connected in series in the former circuit. Because of this big difference in the circuits, the change in the resistance of the transmitter of each set, under the action of the sound waves of speech, produces a greater percent change in the total resistance of the circuit in B than in A.

(2) The greater the variation of the total resistance, the greater is the current in the transmitter circuit. This is the same as saying that the amplitude of the voice current is increased (since the frequency of the speech sound wave is the same). As a result, the voltage of the voice current induced in the secondary winding of the circuit with the induction coil, in B,

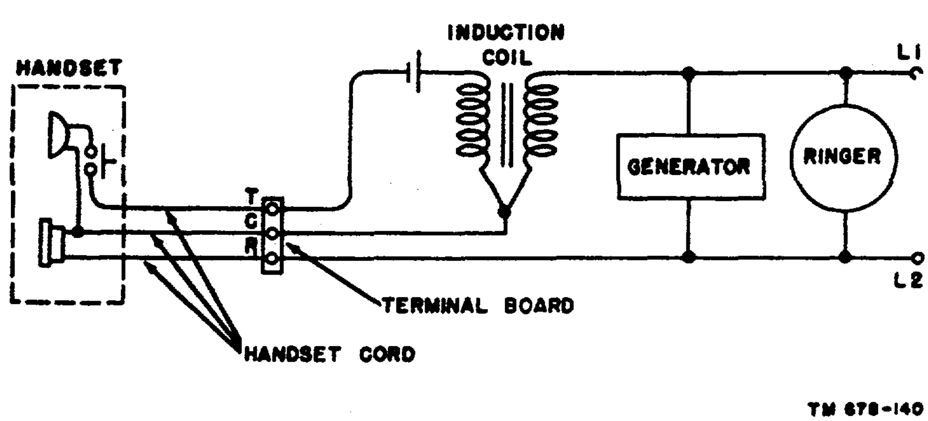


Figure 51. Handset connections of telephone set with induction coil.

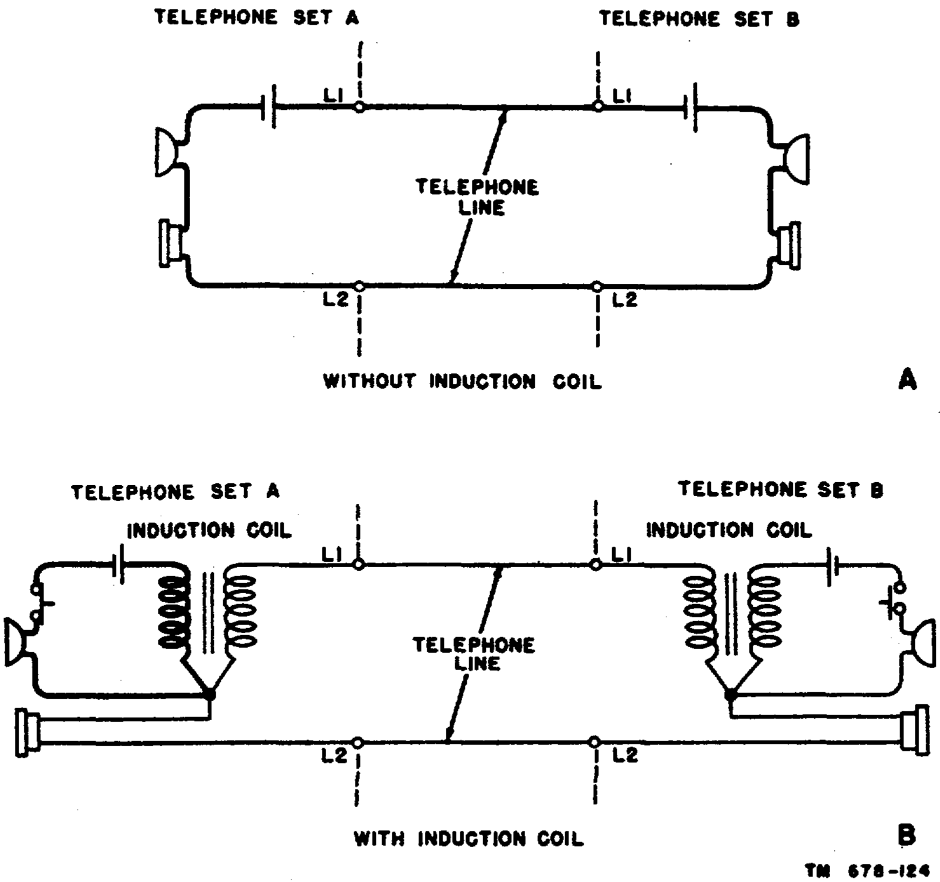


Figure 52. Transmitter circuits with and without induction coils.

is greater than the voltage of the voice current generated by the transmitter in A, the circuit without the induction coil.

e. Advantage in Use of Induction Coil. Because the induction coil, in B, increases the voltage of the voice current generated by the transmitter, it can be used to provide voice conversation over greater distances. The resistance of the talking circuit between two telephone sets becomes greater with increase in the length of the connecting telephone line. Telephone lines have a certain amount of current leakage, and this, too, increases with the length of the line. The greater resistance and current leakage in long telephone lines reduce the voice current in the circuit. The increased voltage produced by the induction coil increases the effective range of practical telephone communications.

49. Structure of Induction Coil

Figure 53 illustrates a typical induction coil, consisting of coils of insulated copper wire wound around a laminated silicon-steel core. The ends of the windings are brought out to terminals mounted on a bakelite insulator. The laminated core minimizes power losses caused by eddy currents induced in the core by the varying voice current. Induction coils are of *closed-core type* and *open-core type*.

a. Figure 53 illustrates an induction coil of the *closed-core type*. The steel core incloses the coils completely, providing a closed magnetic path for the lines of force. Because the magnetic path of this type of coil has less reluctance than that of the open-core type, it is more efficient.

b. An induction coil of the *open-core type* is shown in figure 54. This coil usually has a core made of a bundle of round iron wires which does not provide a complete magnetic path around the coil. Part of the path of the magnetic lines of force passes through the air from one end of the iron core to the other. Because of this, the reluctance of the magnetic circuit is greater, and the magnetic flux less, than that of a closed-core coil with the same current in the winding. The

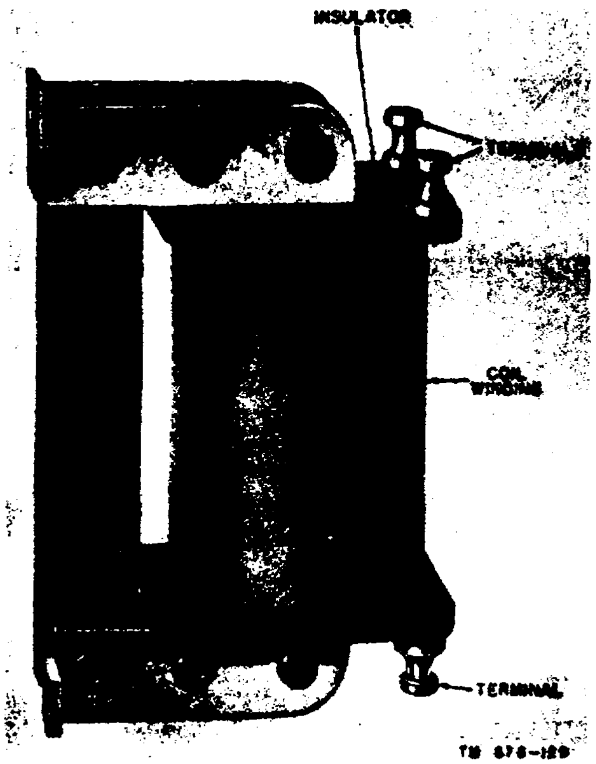


Figure 53. Closed-core induction coil.

open-core coil also has a greater leakage flux; that is, all of the magnetic flux produced by the primary winding does not link the secondary winding. Both of these factors increase the impedance of the coil.

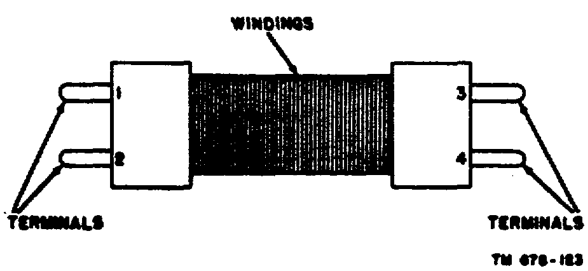


Figure 54. Open-core induction coil.

50. Hand Generator

a. Function of Hand Generator. The *hand generator* enables the telephone user to signal the switchboard when placing a telephone call. It generates an a-c voltage which provides signaling current for operating the signaling device. The signaling device used at the switchboard is the *line drop;* at the called telephone station it is the ringer. The hand generator often is called

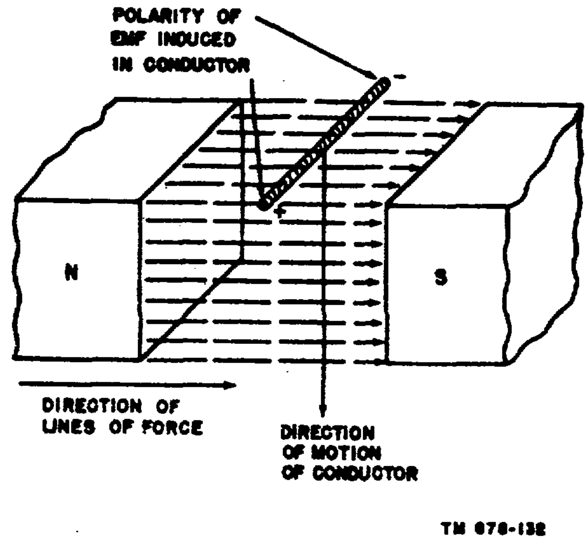


Figure 55. Principle of electromagnetic induction.

the *magneto,* and because it is included in all local-battery telephone sets, local-battery systems sometimes are called *magneto systems.*

b. Principle of Hand Generator. The action of the hand generator depends on the principle of electromagnetic induction, which may be stated as follows: *An emf is induced in a conductor which*

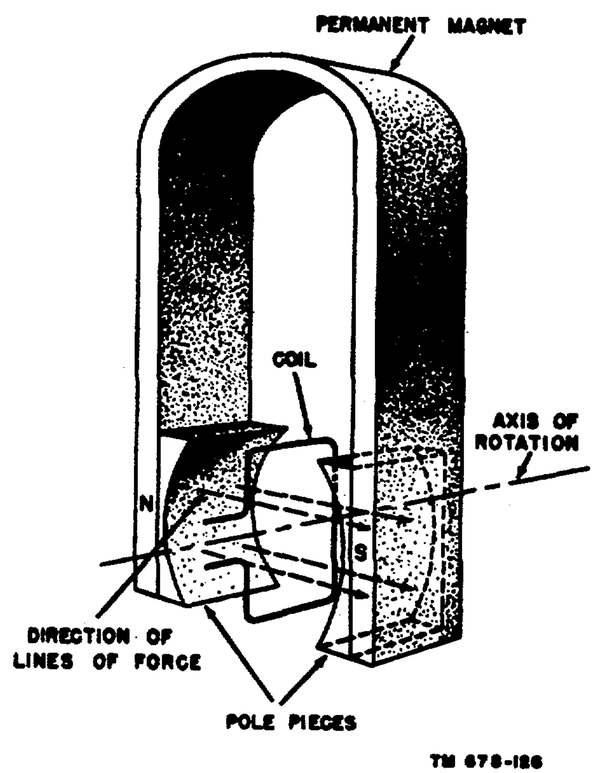


Figure 56. Operating principle of hand generator.

moves in such a way as to cut lines of force in a magnetic field. The induced emf is proportional to the strength of the magnetic field and to the rate at which the lines of force are cut, increasing as the rate at which they are cut increases. The direction of the induced emf depends on the direction of the magnetic field and on the direction of the motion of the conductor through the field. Figure 55 shows this relation. Thus, if the conductor is moving down in a magnetic field extending from left to right (north pole to south pole), the polarity of the induced emf is as indicated.

c. Production of Alternating Current by Hand Generator. Figure 56 shows a conductor that is a single coil of wire fixed to rotate on an axis between the poles of a horseshoe magnet. Attached to the poles of the magnet are *pole pieces* of cast

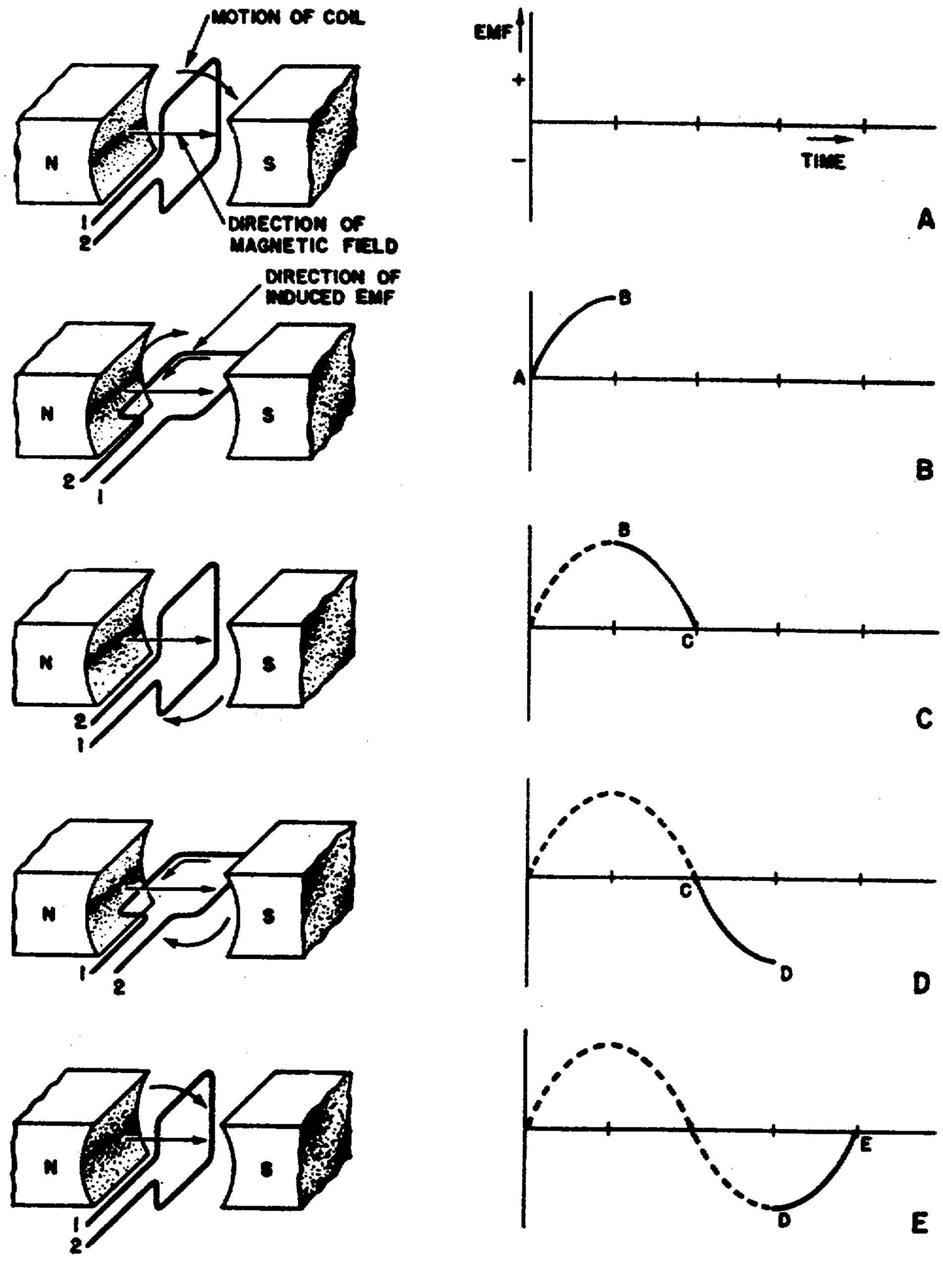


Figure 57. Emf inducted by coil rotating in magnetic field.

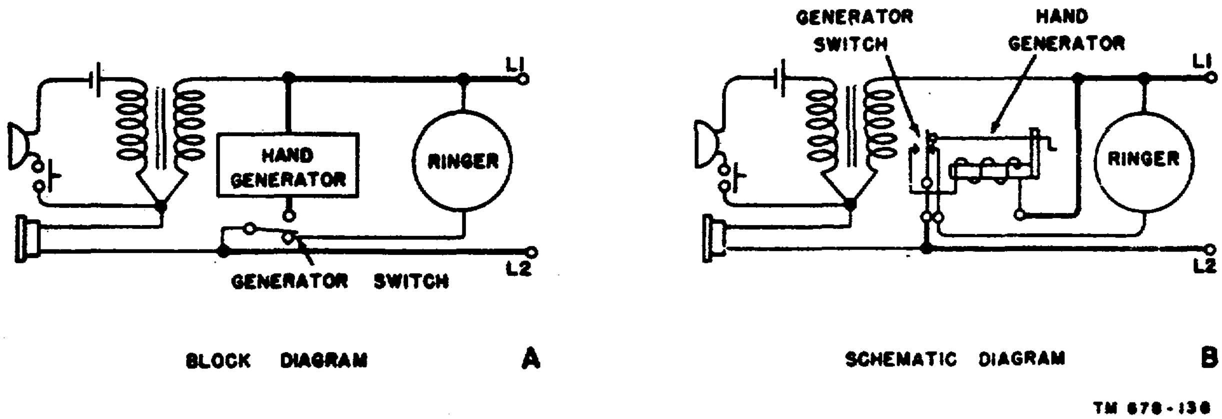


Figure 58. Circuit of hand generator.

iron, used to concentrate the magnetic flux in the space between them. When the coil is rotated, it cuts the magnetic field of the magnet, and an emf is induced in it. Figure 57 shows successive positions of the coil as it rotates between the pole pieces, along with graphs of the waveshapes of the *induced emf* plotted against *time* for the rotation between the successive positions.

(1) When the coil is vertical, as in A, the two sides parallel with the axis of rotation are moving parallel with the lines of force, and are not cutting them; therefore the induced emf is zero. As the coil rotates from this position in the direction of the curved arrow (clockwise), the rate of cutting and, therefore, the induced emf increase until the coil is horizontal, as in B. At this point, the rate of cutting of the magnetic lines of force and, therefore, the induced emf are maximum. As the coil rotates farther, in C, the rate of cutting, and, therefore, the induced emf decrease until the coil is vertical. At this point, the rate of cutting of the magnetic lines and, therefore, the induced emf are zero again. This second vertical position of the coil differs from the first, in that the coil as a whole has undergone a 180° change of position. Terminal 2 is now above terminal 1.

(2) The second half-revolution of the coil repeats what occurred above, except that the induced emf is of opposite polarity to that of the first half-revolution. This is to be expected, because of the reversal of the position of the coil.

(3) Each complete revolution of the coil thus generates 1 cycle of an alternating emf. When the coil is connected through slip rings to a closed, external circuit, this induced alternating emf produces an alternating current in the circuit. A greater induced voltage can be obtained by increasing the number of turns of the coil.

d. Circuit of Hand Generator. In figure 58, A illustrates the generator circuit of a local-battery telephone set, with the hand generator shown as a block. The circuit includes the hand generator and the *hand-generator switch.* In its normal position, the hand-generator switch keeps the hand-generator circuit open and the ringer circuit closed. When the hand generator is used to signal, its operation automatically opens the ringer circuit, preventing signal current from activitating it, and closes the hand-generator circuit, putting the hand generator across the terminals of the telephone set. B shows the same circuit, using the schematic symbol for a hand generator. The symbol includes the hand-generator switch.

51. Structure of Hand Generator

a. Magnets of Hand Generator. The magnetic field in the hand generator illustrated in figure 59 is supplied by *permanent bar magnets* arranged on either side. The magnets are made of alnico, a special steel alloy which has high magnetic retentivity and is capable of providing a strong magnetic field. The magnets are provided with pole pieces located as shown. The rotating coil consists of many turns of fine enamel-insulated wire wound on an iron core. The combination of coil and iron core is called the *armature.*

b. Armature of Hand Generator. Figure 60 shows the construction of the armature of a hand generator. One end of the coil winding is con-

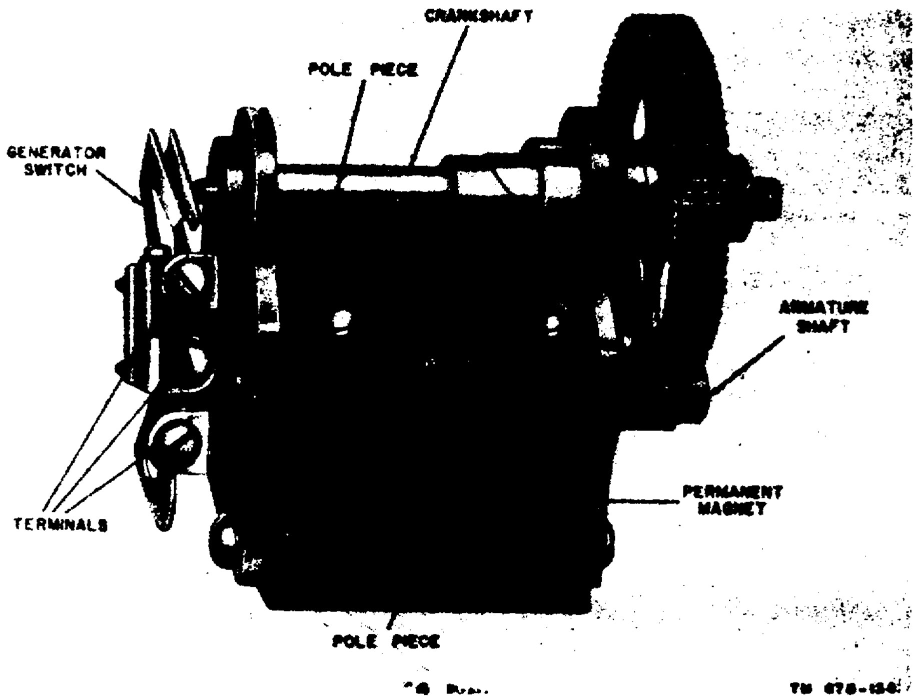


Figure 59. Hand generator.

nected to the armature core and the other end to a pin in the axis of the armature shaft. The pin is insulated from the rest of the shaft. A flat spring (not shown), pressing against the pin, completes the circuit from the armature to one terminal of the hand generator. The frame of the hand generator is in contact with the armature core and acts as the other terminal.

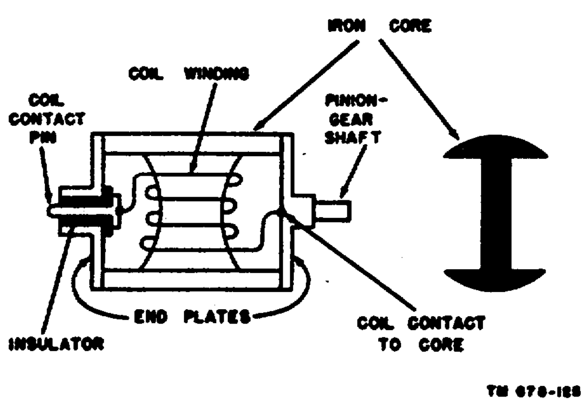


Figure 60. Construction of armature of hand generator.

c. Other Types of Hand Generators. Other types of hand generators have slightly different arrangements for producing the magnetic field. The type shown in figure 41 uses U-shaped or horseshoe-shaped permanent magnets fitted over the pole pieces. The number of magnets used varies from two to five, depending on the size of the hand generator. Another type of hand generator has a fixed armature and a rotating magnet.

d. Hand-Generator Switch. The *hand-generator switch* is fastened to one end of the hand generator (fig. 61). It consists of a pile-up of phosphor-bronze springs separated by insulators. The spring assembly includes the terminals of the hand generator and the contact to the insulated pin of the armature shaft which completes the armature circuit. The switch is operated by the motion of the shaft of the hand generator as the crank is turned.

52. Mechanical Operation of Hand Generator

a. Operation of Hand-Generator Switch.

(1) The *crank* is mounted on a crankshaft extending the full length of the hand generator (A, fig. 61). On the *crankshaft*, free partially to rotate, is a *drive gear* which meshes with a *pinion gear* mounted on the shaft of the *armature* below. The drive gear has an extended hub with a matched end which mates with a V-ended *cam* pinned to the crankshaft. A compression spring, coiled about the crankshaft within a *retaining collar* on

the crank, presses against the drive gear on one side and the crank on the other. In the nonoperating position, the pressure of the spring separates the retaining collar and drive gear, mating the cam in its notch and keeping the tipped extension of the crankshaft from touching the hand-generator switch.

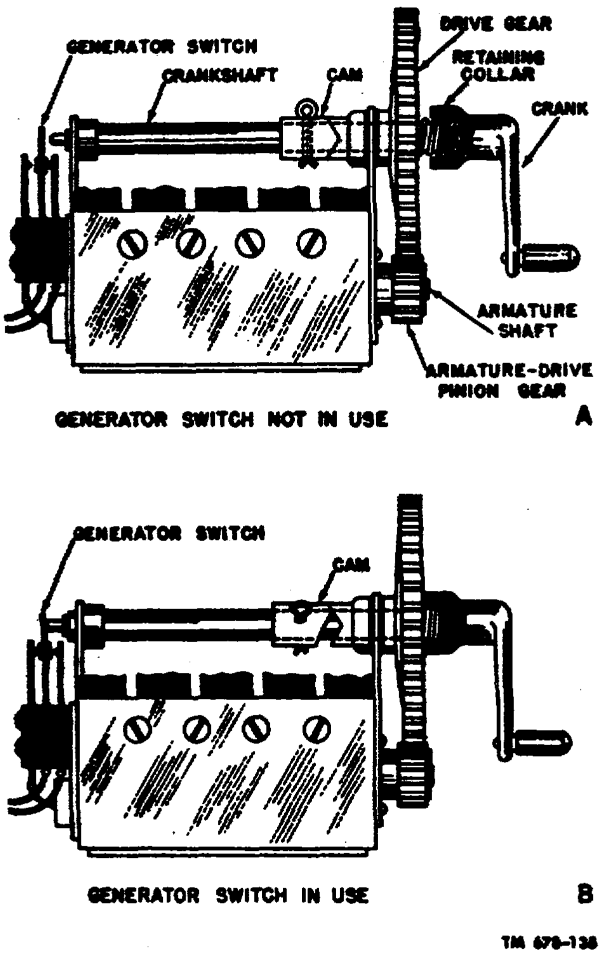


Figure 61. Action of hand-generator switch.

(2) As the generator crank is turned, the magnetic field tends to prevent the armature from rotating. Initially, this magnetic drag through the gears prevents the drive gear from rotating, and the cam rides up the face of its V-notch, forcing the crankshaft to move slightly endwise to the left, as in B. This motion causes the tipped extension of the crankshaft to operate the hand-generator switch, mounted at the left. The retaining collar, by jamming against the drive gear, limits both the motion of the shaft and the travel of the cam up the face of the notch. After it has jammed, further turning of the crank causes the drive gear and armature to rotate. The armature by its rotation in the magnetic field generates the emf for the signaling current. When the crank is released, the compressed spring restores the crankshaft and the hand-generator switch to their nonoperating positions. The pinion gear usually is connected to the armature shaft in such a manner that when cranking has ceased, the armature is free to rotate and aline itself with the field between the poles. This conserves the life of the permanent magnets.

b. Operating Speed of Hand Generator. The hand generators used in local-battery systems develop an emf of approximately 85 to 90 volts at a frequency of 16 to 20 cycles at normal cranking speed. Both the frequency and the generated voltage depend on the speed with which the generator is cranked. Each rotation of the armature produces 1 cycle of alternating current. The gear ratio between the drive gear and the armature pinion gear is about 5 to 1. To produce the required ringing frequency of 16 to 20 cycles with this arrangement, the drive gear must be rotated slightly more than three times per second.

c. A recently designed hand generator which is now being used on many military equipments is shown in figure 62. Electrically, the performance of this generator is comparable to the generator described previously and its functioning is similar. Mechanically, the unit has been modified. The generator is smaller and can be removed from an equipment, disassembled, and serviced with relative ease. When using the generator, the operator has a choice of spinning the dial with his fingers or cranking in the usual manner. The crank is pivoted and can be snapped into a compartment on the face of the dial when it is not being used.

53. Ringer

a. Function of Ringer. The ringer is the signaling device of the telephone set. By sounding, it signals all within earshot that the telephone is to be answered. Usually it is an electric bell which operates on the low frequency of about 20 cycles generated by the hand generator or ringing ma-

A. Unit removed from equipment
B. Unit with cover removed
Figure 62. Hand generator.

chine. (The ringing machine will be described later.)

b. Operating Principle of Ringer.

(1) Figure 63 shows a simplified diagram of the *ringer*. Two electromagnets, coils wound on soft-iron cores, are permanently joined at the upper ends by a soft-iron yoke to form a *horseshoe magnet*. A soft-iron *armature*, pivoted at its center, is placed under the cores of the electromagnets. The armature carries a *clapper rod* and a *clapper* which can vibrate between the two *gongs* (bells). A *permanent magnet* in the form of a shallow U is secured by one end to the yoke; its other end is bent around to lie adjacent to, but not touching, the center

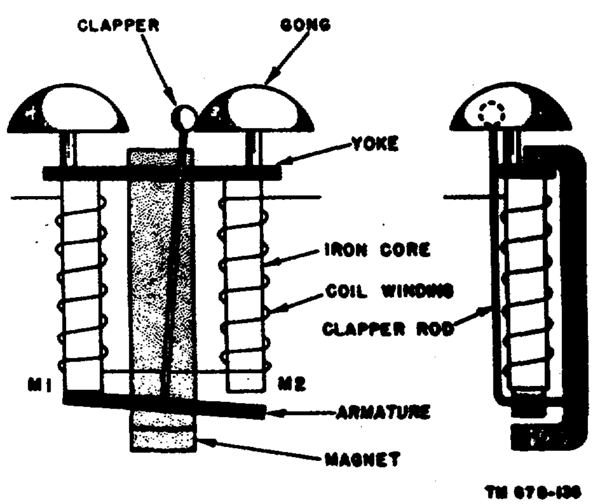


Figure 63. Ringer.

of the armature. The coils of the electromagnet are so wound that when a current passes through them they are magnetized in opposite directions; thus, if the lower end of coil M1 becomes a north pole, the lower end of coil M2 becomes a south pole.

(2) The operating principle of the ringer is illustrated in figure 64. When there is no current in the ringer, the cores and armature are magnetized by the permanent magnet, and the path of the magnetic flux is as shown in A. If the upper pole of the magnet is assumed to be a north pole, the flux of the permanent magnet has a path through the yoke, the cores of the electromagnets, the air gap between the cores and the armature, the armature, and the air gap between the armature and the south pole of the permanent magnet. Since the reluctance of the magnetic path is the same through either core, the magnetic lines of force distribute evenly between them; the magnetic pull of the cores on the armature is equal, and the armature occupies the balanced position shown.

(3) Alternating current through the ringer upsets this magnetic balance. Since the current changes direction each half-cycle, one core alternately is made magnetically stronger than the other. If the current direction for the first half-cycle of ringing current is taken as shown in B, the magnetic flux in core M1 is strengthened, whereas that in core M2 is weakened. This results in an increased pull on the armature by core M1, which attracts the left end of the armature and causes the clapper to strike the right gong.

(4) In the second half-cycle, in C, the current reverses its direction. The magnetic flux in core M2 now is strengthened, and that in core M1 is weakened. As a result, the right end of the armature is attracted by the greater magnetic pull of core M2, causing the clapper to strike the left gong. The continuous change in the direction of the current thus alternately attracts the armature to one core and then the other, causing the clapper to vibrate between the gongs. Because of the initial magnetic field set up by the permanent magnet, such ringers are termed *polarized ringers*.

c. Structure of Ringer. Figure 65 illustrates a

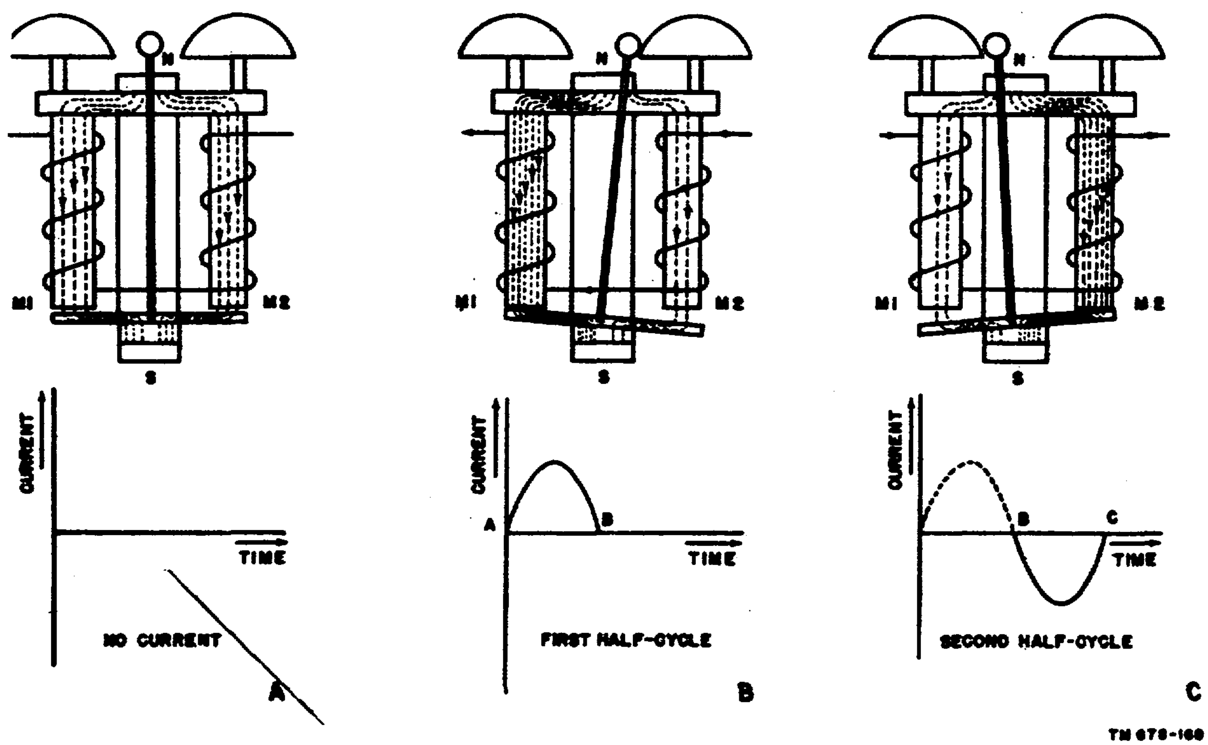


Figure 64. Operating principle of ringer.

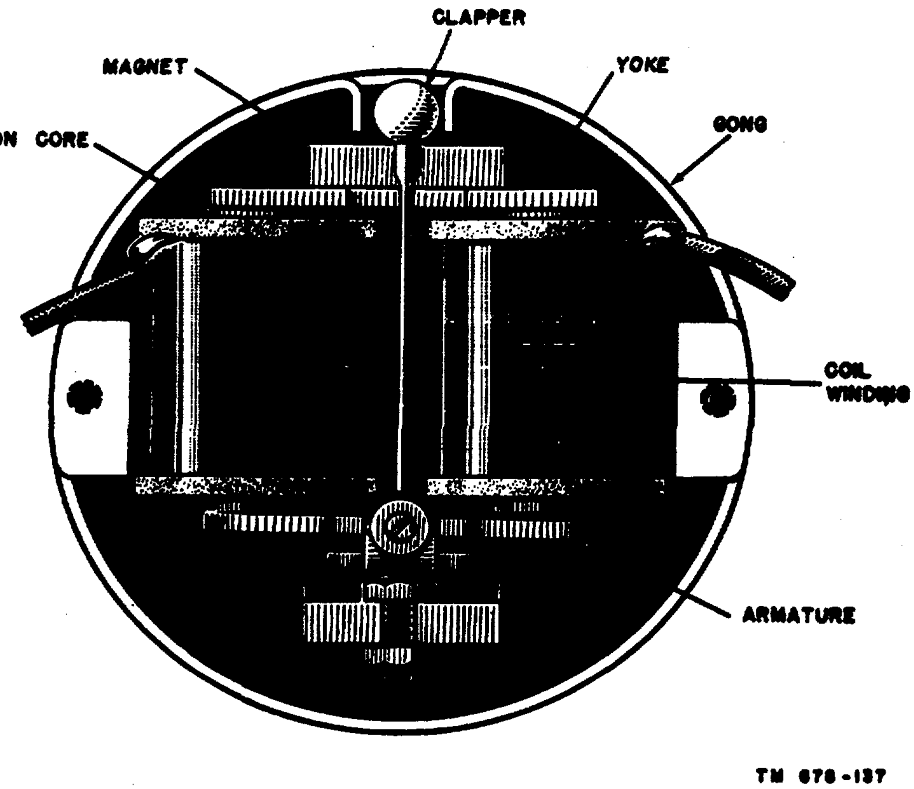


Figure 65. Local-battery ringer.

typical local-battery-telephone ringer. The coils are wound of many turns of fine enamel-insulated wire. Externally, they are wrapped with soft cotton fiber as a protection against mechanical injury, and then impregnated with varnish to keep out moisture. The two coils in series have a d-c resistance of 1,300 ohms and an impedance, at 1,000 cycles, of 18,750 ohms. The yoke, electromagnet cores, and armature are made of soft iron which retains very little magnetism when the magnetizing current or the permanent magnet is removed. The ringer has a single gong with a split section between which the clapper vibrates. The gong and clapper usually are made of brass. The ends of the armature are fitted with brass tips, to prevent residual magnetism from causing them to stick to the core ends.

d. Circuit of Ringer. Figure 66 shows the *ringer circuit* of the local-battery telephone set. It includes the ringer and the hand-generator switch. In the normal position, the hand-generator switch connects the ringer across the terminals of the set.

54. Signaling Circuit

Figure 67 shows the *signaling circuit* of two local-battery telephone sets. It includes the hand generator and the hand-generator switch of telephone A, the telephone line, and the hand-generator switch and ringer of telephone B. To call telephone B, a person at telephone A first turns the crank of the hand generator. This closes the hand-generator switch and puts the hand generator across the telephone line. The hand gen-

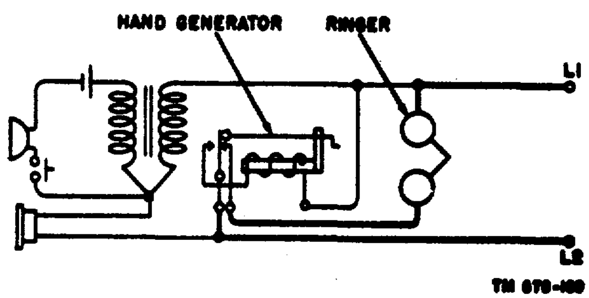


Figure 66. Circuit of ringer.

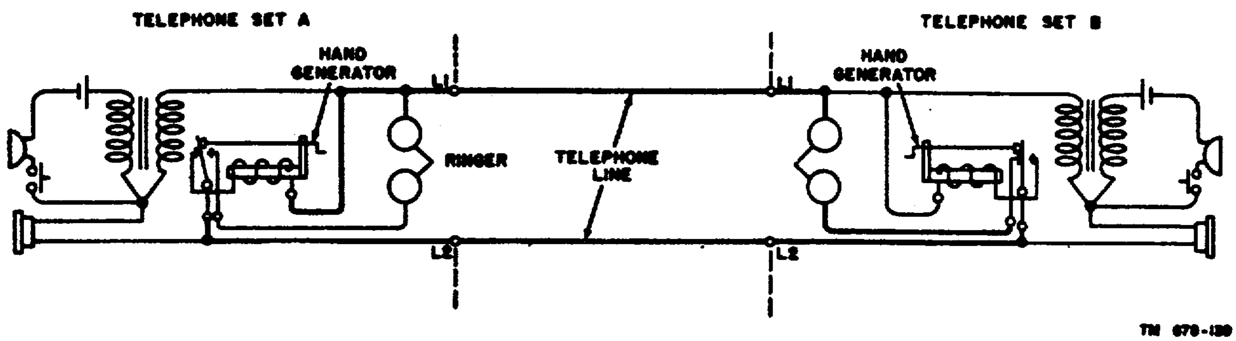


Figure 67. Signaling circuit of two local-battery telephone sets.

erator sends a 20-cycle ringing current to the ringer at B through the connecting circuit provided by the line and the hand-generator switch of B. The sounding of the ringer signals someone at B to answer the telephone. When the telephone is answered, the conversation proceeds. Both ringers are connected across the telephone line during the talking period, but their high impedances prevent the shunting of the voice currents through them. Of course, at the end of the ringing, the hand-generator switch of telephone A opens its hand-generator circuit, leaving the hand generators at each telephone disconnected from the talking circuit. Because each hand-generator switch keeps its hand-generator circuit disconnected at all times except during ringing, it also prevents the shunting of the ringing current through its hand generator when its ringer is activated. The armature of the hand generator has a lower impedance than the ringer; if it were not removed from the line, the shunting of signaling current through it would weaken the response of the ringer.

55. Capacitor

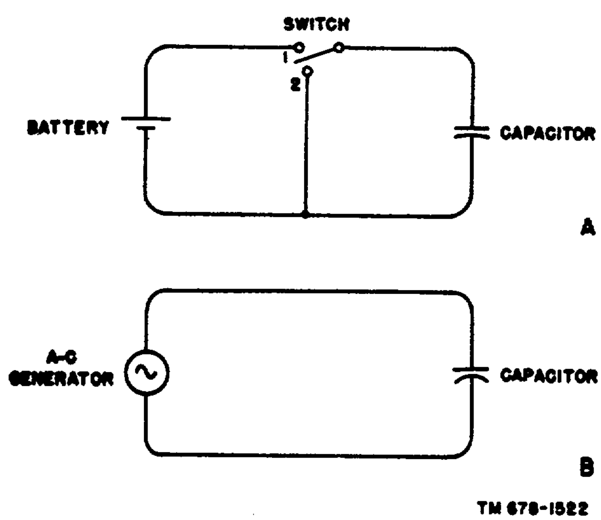
A capacitor is an electric device of many purposes, among which are the coupling of alternating-current circuits and the blocking of direct current. It consists of two conductors called *plates*, or *electrodes*, between which exists, or is inserted, an insulating material called a *dielectric*.

a. Use in Telephone Circuit. In the local-battery telephone set, a capacitor is used to reduce or limit the 20-cycle ringing current through the telephone receiver.

b. Principle. The principle of the capacitor depends on its ability to store an electric charge. When a capacitor is connected to a source of emf, it takes electrical energy from the source and stores it in the form of an electric field, established between the plates. The effect of a capacitor on current in the circuit depends on whether the current has a direct or an alternating source of voltage.

(1) *D-c voltage.* A, figure 68, shows a circuit containing a capacitor, a two-position switch, and a battery. The switch is between positions 1 and 2, and the circuit is open. Now, assume that the switch is thrown to position 1, connecting the battery across the terminals of the capacitor. Instantly, there is a flow of electrons between the battery and the plates of the capacitor. The electron flow constitutes a charging current which makes the voltage across the capacitor equal to that of the battery. As soon as the capacitor voltage equals that of the battery (almost instantaneously) the electron flow stops and the battery supplies no more current to the circuit. The capacitor has taken electrical energy from the battery and is now storing it in the form of an electric field, set up and maintained between its plates. The capacitor can return this stored energy to the circuit. For example, if the switch now is thrown to position 2, the capacitor discharges, releasing its stored energy through the circuit connecting its terminals. The direction of the discharging current is opposite to that of the charging current, and the voltage across the capacitor falls to zero. The *amount of charge* a capacitor will take depends on its capacitance and the voltage of the source to which it is connected. The capacitance is determined

by the size, structure, and materials of the capacitor—that is, the area of its plates, the distance between the plates, and the dielectric material separating the plates. It increases with increase of the area of the plates and with decrease of the distance between them. The effect of the dielectric depends on the insulating value of the material of which it consists. A capacitor having a dielectric with a greater insulating value, such as mica, has a higher capacitance than one of equal dimensions but with a poorer insulating value, such as dry paper. The unit of capacitance is the farad. Since the farad is too large a unit for general electronic use, capacitance usually is expressed in μf (microfarads). (One μf is one-millionth of a farad.) A capacitor takes a full charge almost instantly when a d-c voltage is applied; however, if resistance is connected in series with the battery and the capacitor, the time required fully to charge or completely to discharge the capacitor is increased. Except for the initial charging current, there is no current in the capacitor circuit when a d-c voltage is applied.



A. Direct current.
B. Alternating current.

Figure 68. Capacitor circuits.

(2) *A-c voltage.* B, figure 68, shows an a-c generator connected to the terminals of a capacitor. The generator supplies a sine-wave a-c voltage. Thus, the voltage across the capacitor rises to a maximum and falls to zero first in one direction and then in the opposite direction. During a complete cycle of the generator voltage, this voltage makes one plate of the capacitor positive for one half-cycle and the other plate positive for the next half-cycle. Therefore, in the circuit between the generator and the capacitor, there is a continuously varying flow of electrons first in one direction and then in the opposite direction, which constitutes an alternating current. Although there is alternating current *in the circuit* there is none *through the capacitor.* The *frequency* of the alternating current in the circuit (fig. 68) is the same as that of the a-c voltage of the generator. The *amount* of current in the circuit, however, is determined by the capacitor, which tends to oppose the presence of the current. The opposition of the capacitor to the current is termed *capacitive reactance*, and it depends on the frequency of the applied voltage and the capacitance of the capacitor. The capacitive reactance is higher for lower frequencies and higher for smaller values of capacitance. Because the capacitive reactance is large at the lower frequencies, the a-c current in a circuit is reduced by adding a capacitor to the circuit. A more complete discussion of the capacitor is included in TM 11-681.

56. Structure of Capacitor

Figure 69 shows the structure of one type of capacitor. Each of the two plates is a thin sheet of tinfoil, to which a lead (wire) is attached for the purpose of making connections. The plates are separated by a sheet of waxed paper. To save space, the tinfoil plates and the waxed-paper insulator are formed into a flattened rectangular roll. The roll then is inserted in a metal can which is filled with wax and then sealed to keep moisture out. The connecting wires are brought out to insulated terminals mounted on one face of the can. Figure 70 shows three capacitors used in local-battery telephone circuits; the one with the four terminals is actually three capacitors mounted in one metal can. Other capacitors used in telephone circuits have mica as an insulator

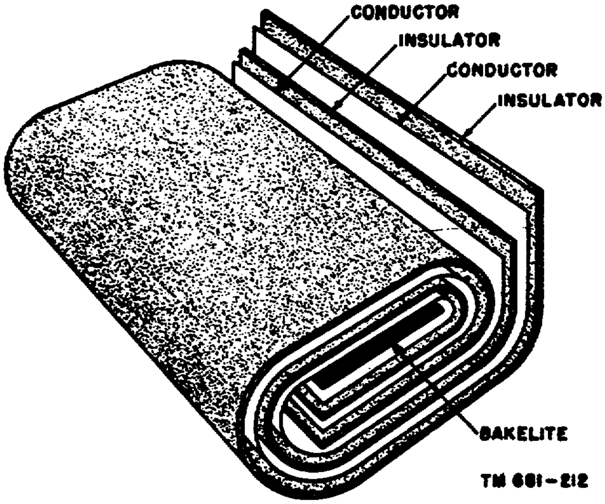


Figure 69. Structure of capacitor.

between the metal coil. They are more stable with changes in temperature than waxed-paper capacitors, their value of capacitance usually is more precise, and they can withstand larger operating voltages.

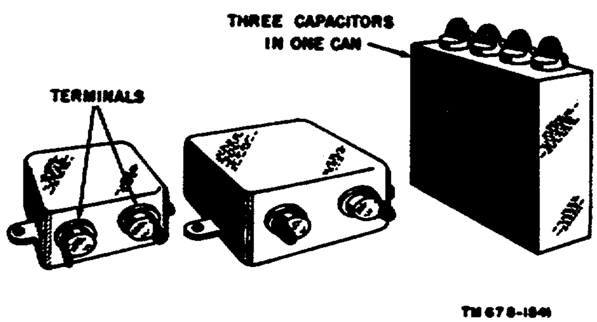


Figure 70. Capacitors.

57. Capacitor in Telephone Circuit

a. Figure 71 shows the circuit of a local-battery telephone set with capacitor C1 in the receiver circuit (heavy lines). This capacitor usually has a capacitance of .5μf. It has a high capacitive reactance at the 20-cycle frequency of the signaling current, but a relatively low capacitive reactance at the 200- to 2,700-cycle frequency (approximately) of the voice current. The high capacitive reactance at the low signaling frequency increases the impedance of the receiver circuit for the signaling current, whereas the impedance for the higher-frequency voice current remains relatively unchanged. Thus, the voice current to the receiver is not affected by the capacitor.

b. If there were no capacitor in the receiver circuit (fig. 71), the circuit of the telephone receiver and the secondary winding of the induction coil would have an impedance lower than that of the ringer. Since the receiver circuit is in parallel with the ringer circuit, it would provide an additional path for the signaling current, so that when a distant telephone set signaled, a large part of the signaling current would be shunted through the receiver circuit. This would reduce the current through the ringer and decrease its volume of sound. Thus, the capacitor, by limiting the amount of 20-cycle signaling current through the receiver circuit, prevents the weakening of the ringer response.

c. In the same way, the capacitor prevents a reduction in the amount of a signaling current transmitted to a distant telephone set (fig. 71). Rotation of the hand generator removes the ringer from the circuit and places the generator in parallel with the receiver circuit. If the capacitor were not in the receiver circuit, part of the signaling current would be shunted through the receiver circuit. This of course would result in less signaling current at the distant telephone set.

58. Sidetone

a. Sidetone is sound transmitted through a local path from the transmitter to the receiver of the same telephone set. This effect was pointed out in connection with the circuit of figure 50 (par. 48). Sidetone results when two telephone sets such as

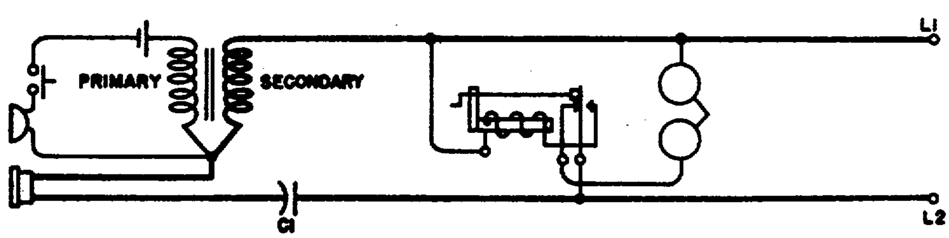


Figure 71. Capacitor in telephone circuit.

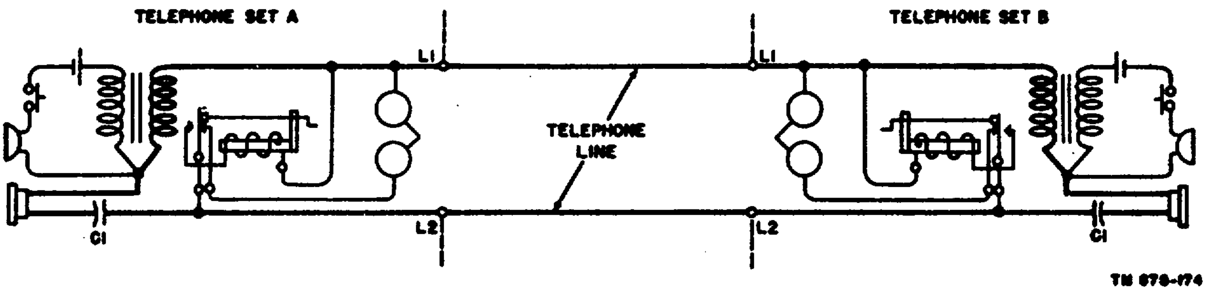


Figure 72. Sidetone circuit.

those of figure 71 are connected as in figure 72. The heavy lines of the latter figure show the mutual path of the voice current in the receiver circuits of the two telephone sets. Both telephone receivers are connected in a series circuit along with the secondary windings of both induction coils, both capacitors, and the connecting telephone line. The voice current produced in this circuit by a person speaking at either telephone passes through both receivers and is reproduced as a sound wave of speech in each one. Persons at both telephones therefore hear their own voices reproduced in their own receivers.

b. Although the receivers in figure 72 are connected in series, the voice current in the telephone set of the speaker is greater than the voice current in the set of the listener. Two factors contribute to make this difference. One factor is current leakage from the telephone line connecting the two telephone sets. Such leakage will be explained in a later chapter. Because of this current leakage, the sidetone in the receiver of the speaker is louder than his words in the receiver of the listener, and the voice of the speaker sounds louder to him than it does to the listener. The other factor is increase of the voice current in the secondary winding caused by the transformer action of the induction coil. This increased voice current, passing through the receiver of the speaker, further increases its output of sidetone.

c. A loud sidetone is undesirable in the telephone set for three reasons. First, when the speaker hears his own voice loudly reproduced by the receiver, he usually lowers his voice. This reduction of the sound input of the transmitter reduces its voice-current output, which in turn reduces the current in the receiver of the distant telephone set. Second, the amplified and comparatively loud tones reproduced in the receiver of the speaker tend to lessen the sensitiveness of the ear of the speaker to the more feeble voice current from the distant telephone set. Third, local room noise is picked up by the transmitter and is heard by the local listener along with the voice of the distant speaker. These surrounding noises, reproduced in the local telephone receiver, both distract the listener and reduce the intelligibility of the words he hears. The effect is particularly objectionable when the telephone is used in unusually noisy locations. Many antisidetone circuits greatly reduce the undesirable effects of sidetone. One, commonly used by the Army in local-battery telephone, will be described.

59. Principle of Antisidetone Circuit

An *ideal* antisidetone circuit is one that prevents the passage of voice currents from the transmitter to the receiver of the same telephone set. However, a path is provided to the receiver for voice currents originating at a transmitter of a distant telephone set. This means that a person talking into a telephone set equipped with an ideal antisidetone circuit cannot hear his own voice in the receiver, but can hear in his receiver the voice of a person at the other end of the line. In actual practice, an ideal antisidetone circuit is not obtainable, and, even if it were, it would not be desirable. There is a good psychological reason for this. It has been found that it is advantageous for the speaker to hear his voice faintly in his receiver, which assures the speaker that his telephone set is in proper working order. In the explanation which follows, the ideal antisidetone circuit will be considered.

a. A, figure 73, shows a d-c Wheatstone-bridge circuit. The four resistors, R1, R2, R3, and R4, called the *arms* of the bridge, are connected to a battery. A galvanometer—a current-indicating instrument—is connected to junction points A and B. Current from the battery is supplied resistor branches R1–R2 and R3–R4; consequently, there is a potential difference (voltage) across

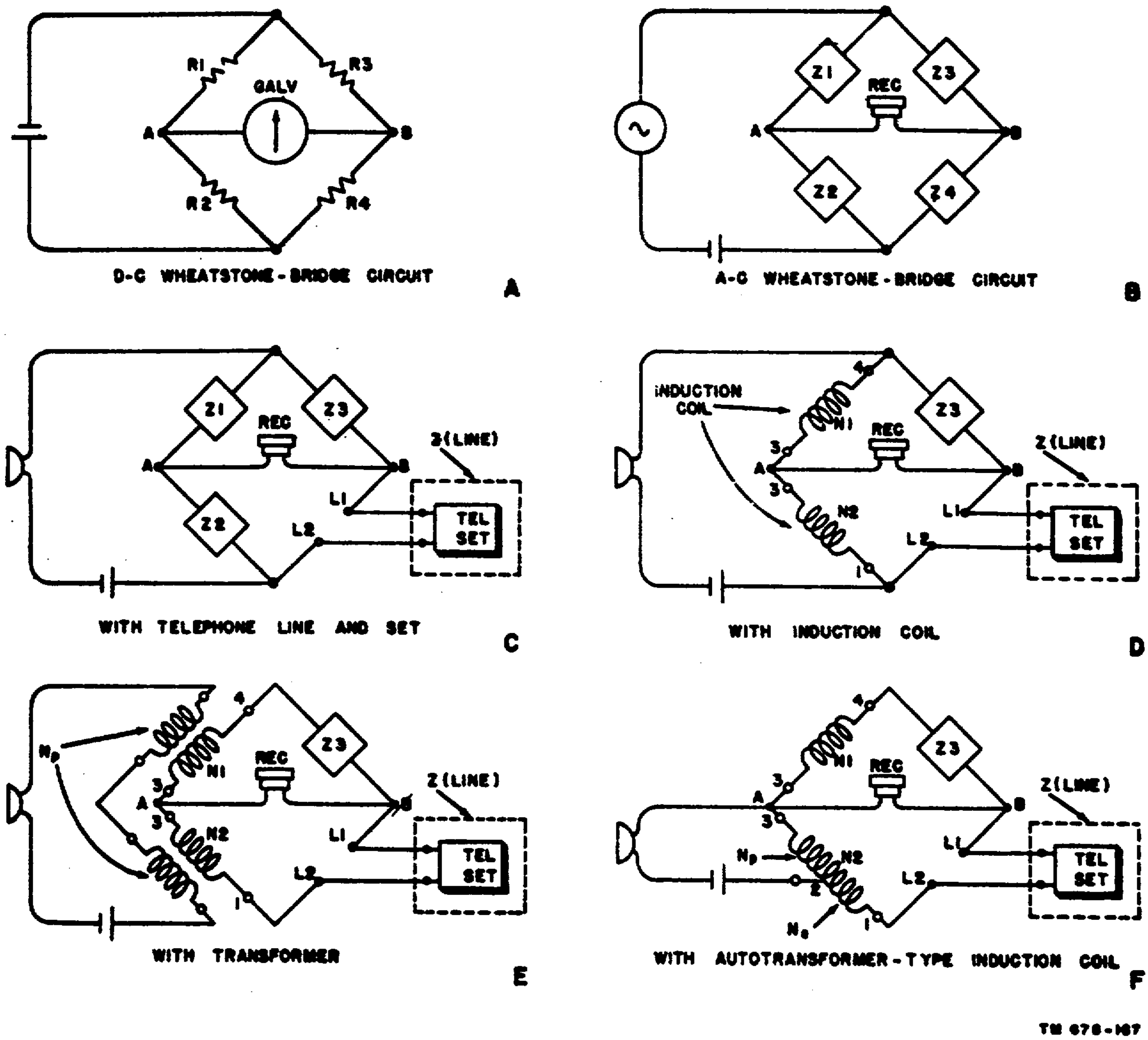


Figure 73. Development of antisidetone circuit.

each of the resistors. When, in addition, there is a potential difference between points A and B, current passes through the galvanometer and causes it to deflect. The bridge is said to be balanced when there is no potential difference between points A and B, and the galvanometer does not deflect. This occurs when the values of the resistors are such that the ratio of R1/R2 equals ratio R3/R4. Thus, when the bridge is balanced, there is no current through the galvanometer.

b. In B, the resistors are replaced by impedances which, in addition to resistance, have inductive or capacitive reactance; the battery is replaced by an a-c since-wave generator, and the galvanometer is replaced by a telephone receiver. This arrangement constitutes an a-c bridge circuit, which, when balanced, passes no current through the receiver. The a-c voltage supplied by the generator is of fixed frequency. When the bridge is not balanced, there is a potential difference between points A and B, and this produces an alternating current through the receiver and causes sound in it. When the ratio of the impedance, Z1/Z2, equals that of Z3/Z4, however, the bridge is balanced, and there is neither current nor sound in the receiver.

c. In place of the a-c generator, a transmitter and a battery may be used as the source of a-c voltage, as in C. Also, in place of impedance Z4, the impedance of a telephone line and connected tele-

phone set, Z(line), may be used. If Z(line) equals Z4, the bridge still is balanced, because the ratio of impedance Z1/Z2 now equals that of Z3/Z(line). When a voice-current voltage is generated by the transmitter, there is no current through the receiver, and it does not sound, but there is a voice current in each of the impedances of the bridge circuit, one of which is the telephone line and the connected telephone set Z(line). This voice current is reproduced by the receiver of the telephone set, but not by the receiver of the bridge circuit. On the other hand, voice current from the transmitter of the connected telephone set produces a response in the bridge receiver. This response occurs because the bridge is not balanced for a voltage applied between terminals L1 and L2. The bridge arrangement in C can be used as the circuit of a telephone set which eliminates sidetone, provided the condition of balance is satisfied at all voice-current frequencies. In practice, it is impossible to secure an exact balance over the entire range of voice frequencies, because the impedances of the components of the circuit vary with frequency; but, for any given telephone line, the balance can be so adjusted that the sidetone is small. Since the impedance of the transmission line is considered one of the components of the antisidetone circuit, the efficiency of the circuit depends in part on the length of the line connecting the two telephone sets.

d. When transmitting with this circuit, part of the energy of the voice current is wasted in impedance arms Z1 and Z2 as well as in Z3 and Z(line). However, by substituting windings N1 and N2 of a transformer or induction coil, as in D, the loss of energy can be reduced. If N1 and N2 were the windings of an ideal transformer—if they had negligible resistance—no energy would be wasted in them; all the energy would be used in impedances Z3 and Z(line).

e. The induction coil in D can be replaced by one having a separate primary winding, N, as in E. This does not change the bridge action of the circuit, but it permits the voltage of the voice current generated by the transmitter to be stepped up or down effectively in any desired ratio by choice of the proper number of primary turns. Thus, a transmitter of any resistance can be used efficiently. In an actual telephone set, the element Z3—which may consist of a noninductive resistance—is combined physically with the resistance of winding N1.

f. The circuit with the type of induction coil called an *autotransformer* is shown in F. An autotransformer is a transformer, the primary and secondary of which are part of the same winding. An a-c voltage applied across a portion of the turns of the autotransformer induces an a-c voltage in the full winding, because the autotransformer is so designed that the varying magnetic flux in the turns to which the voltage is applied links all the other turns. As in the case of a standard transformer, the primary winding is the one to which the voltage is applied, and the secondary is the one in which the voltage is induced. N1 and N2, in F, are parts of a single winding, with intermediate connections at points 2 and 3. The voltage of the voice current generated by the transmitter is applied across points 2–3, part of winding N2. This part of the winding, N2, is therefore the primary winding, Np, of the autotransformer. The varying voice current in Np induces a voltage in winding N1–N2. This induced voltage is greater than that applied to the primary winding, Np, because winding N1–N2 has more turns than winding Np. The use of an induction coil of the autotransformer type produces a step-up in the voltage of the voice current which appears at terminals 1–4 of secondary winding N1–N2. In this circuit, since the transmitter is connected across the same number of turns (Np) as in the circuit shown in E, the action is essentially the same. Use of the autotransformer, however, does result in a slightly more efficient circuit.

60. Operation of Antisidetone Circuit

a. Figure 74 shows the circuit between two local-battery telephone sets with antisidetone circuits and also the actual relation of the coil windings. The induction coil is of the autotransformer type with a continuous winding wound in the same direction between terminals 1 and 4. The coil has connections on the winding at intermediate points 2 and 3. These connections, together with the end connections, 1 and 4, are brought out to terminals mounted on the coil frame. In the antisidetone circuit the transmitter, handset switch, and battery are connected to terminals 2 and 3. Winding 2–3 is the inner winding, or primary, of the coil. The receiver is connected to terminal 3 and one terminal of capacitor C2. Winding 3–4 is part of the outer winding of the induction coil. The secondary is the complete coil between terminals 1 and 4. The terminal notations of figure 74 are similar to those in F, figure 73. Capacitor C2 is

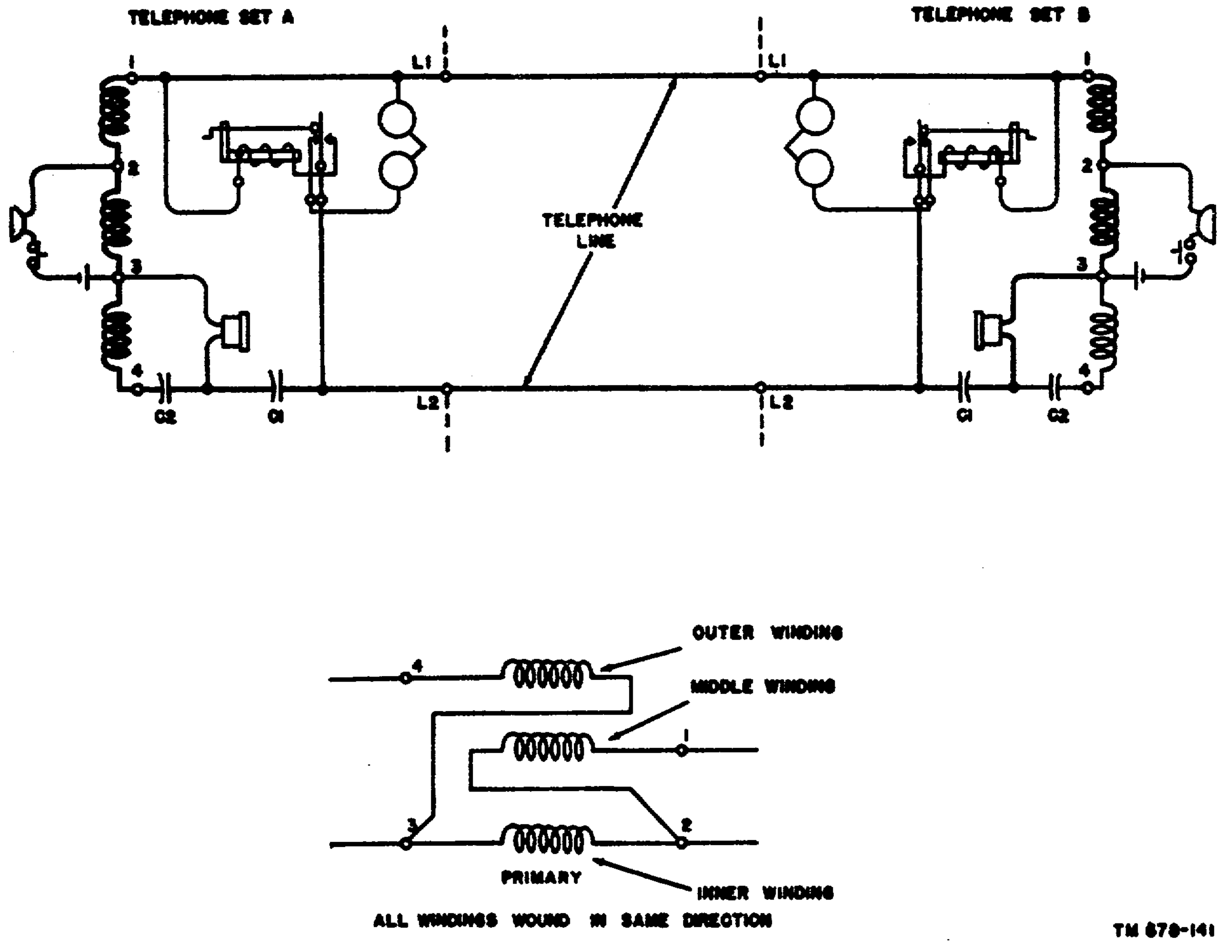


Figure 74. Simple telephone system showing antisidetone circuits, and arrangement of windings in induction coil.

part of impedance Z3 of that figure; its resistance portion is included as the resistance of winding 1–2 of the induction coil. This winding, together with capacitor C2, is called the *balancing network* of the bridge circuit.

b. The heavy lines in figure 74 show the complete talking circuit between the two local-battery telephone sets. A person speaking into the transmitter of telephone A produces a varying voice current in the 2–3 winding of the induction coil. This induces a voice-current voltage across terminals 1–4 which provides a voice current in the circuit of the transmission line and telephone set B. For the voice-current voltage applied to the 2–3 winding, telephoneA, the line, and telephone B form a balanced-bridge circuit for the receiver of telephone A. As a result, the voltage between point 3 and the straight-line plate of capacitor C2 is zero, and there is no voice current through the receiver of telephone A. At telephone B, however, the voice current results in a voltage across the L1–L2 terminals; the bridge circuit is not balanced for a voltage applied across these points; therefore there is voice current through the receiver of telephone B. The circuit functions in the same manner when the transmitter of telephone B provides voice current in the circuit to telephone A, except that the situation is reversed. The receiver of telephone B then is across the balanced-bridge circuit for the voice-current voltage of its transmitter. There is no current through receiver B, but there is current through receiver A. Thus, the antisidetone circuit reduces sidetone by preventing the voice current of the local transmitter from passing through the local receiver.

c. Another explanation of antisidetone action can be obtained by considering the simplified circuits of figure 75. The transmitter and its battery are connected, in A, to terminals 2 and 3 of the

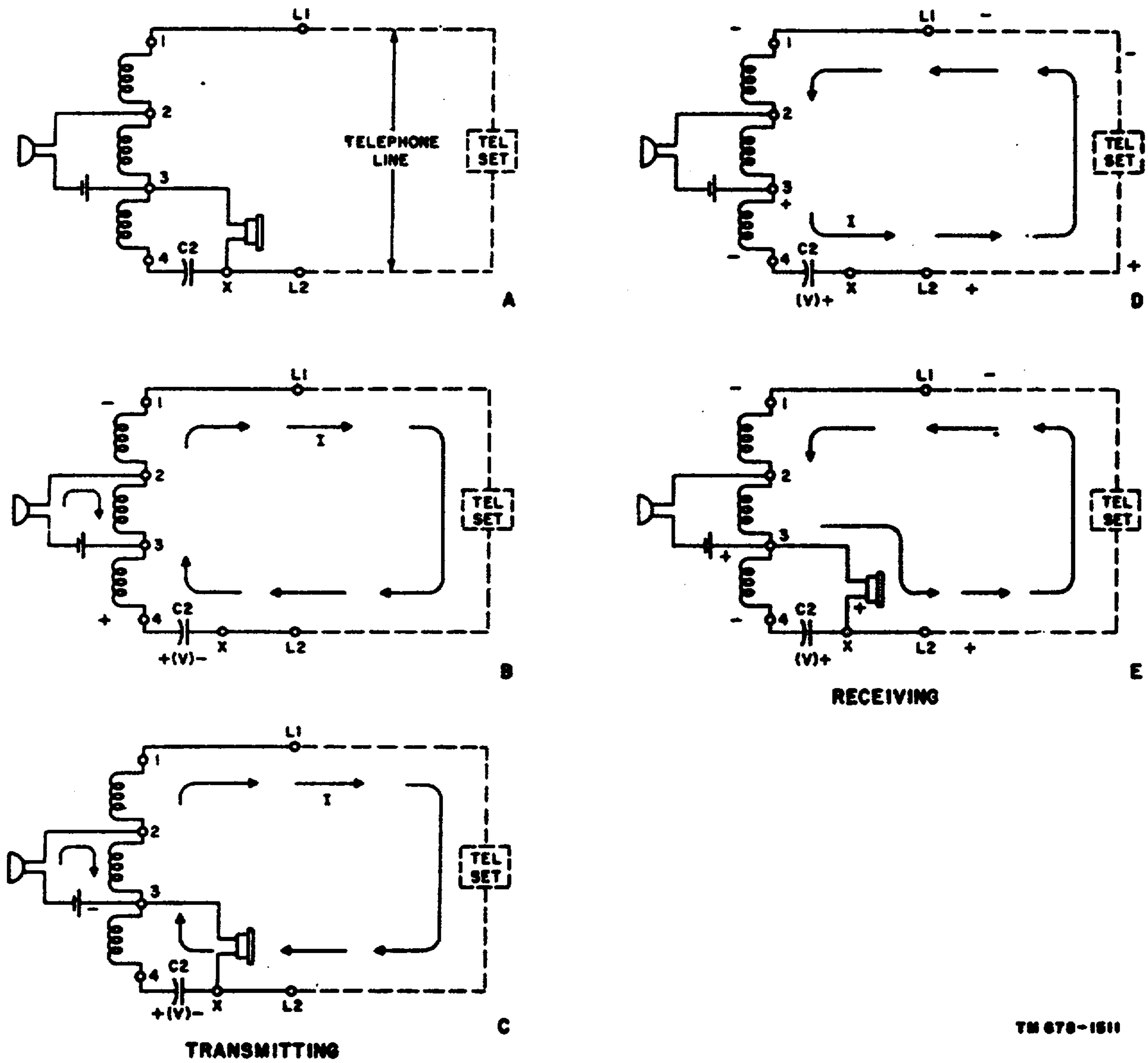


Figure 75. Antisidetone action, functional diagrams.

autotransformer. The secondary of the autotransformer is the complete winding between terminals 1 and 4. The receiver is connected to terminal 3 of the autotransformer and to one side of capacitor C2. Capacitor C2 is necessary to complete the antisidetone action.

(1) *Transmitting.* To show the reason for the location of the receiver in the circuit, assume first that the receiver is omitted, as in B. When a person speaks into the transmitter, a varying voice current is set up in the 2–3 winding of the autotransformer. This action results in a varying voltage between terminals 1 and 4 (the secondary) of the autotransformer. To simplify the explanation, consider an instant of time when the polarity of the induced voltage is as shown, with terminal 1 negative and terminal 4 positive. This voltage causes a current to flow through the external circuit, which consists of the telephone line and the distant telephone set, capacitor C2, and the autotransformer. The direction of current flow through the circuit is from the negative terminal to the positive terminal of the voltage source. As a result of this current, a voltage, V, which has the polarity shown, is developed across capacitor C2. By prop-

erly designing the circuit, the voltage V, can be made equal to the induced emf of winding 3–4 of the autotransformer, but polarities of the two voltages are opposite. Thus, between point 3 on the autotransformer and point X on the diagram there is zero *difference* in potential. If, now, the receiver is connected to these two points, as in C, no current will flow through the receiver, since there is no voltage difference across it. Therefore, by placing the receiver in this location, a person speaking into the transmitter of the ideal antisidetone circuit does not hear his own voice in his receiver. For complete sidetone elimination, it is necessary for the voltage, V, developed across capacitor C2 to be exactly equal to the emf of the 3–4 winding of the autotransformer. This condition seldom occurs in actual practice because certain factors tend to change the voltages. First, the different voice frequency currents transmitted will vary the impedance of the telephone line and distant telephone set in addition to changing the reactance of capacitor C2. Different impedances cause different voltage drops throughout the circuit. Second, if a telephone line with a different impedance is used in place of the original telephone line, the different impedances will change the voltage drops throughout the circuit. Still other changes in voltage in the circuit would occur if the distant telephone were replaced by a telephone the impedance of which is not the same as the original telephone set. Since these conditions exist in practical telephone circuits, it is possible to reduce sidetone but never to eliminate it. However, as explained in paragraph 59, some sidetone is desirable.

(2) *Receiving.* In receiving, as in D and E, the source of voltage is from the circuit of the distant telephone set, which impresses a voltage across terminals L1 and L2. Now, consider an instant of time when the distant telephone applies a voltage across L1 and L2, as in D. The current flow that results from this applied voltage causes a voltage drop, V, across capacitor C2, plus a voltage drop across terminals 4–1 (now the primary) of the autotransformer. The autotransformer winding, 1–4, is now a part of the load (a receiver of voltage); whereas, in transmitting, it was a part of the source of voltage. This means that, in receiving, the voltage of winding 3–4 will have the same polarity as the voltage, V, and the two voltages will aid each other. Thus, in receiving, a potential difference exists between terminal 3 of the autotransformer and point X of the diagram. If the receiver again is connected to these points, as in E, current will flow through the receiver. Current takes the path through the receiver instead of the alternate path X–4–3 (actually a small amount of current does follow path X–4–3) because the impedance offered to the flow of current by the receiver is considerably lower. Therefore, the antisidetone circuit provides a path to the local receiver for voice currents originating at the distant telephone set.

61. Local-Battery Switchboard

a. Purpose. Communication between two telephone stations can be effected through a connecting telephone line, but practical communication among many telephone stations requires that the telephone line from each one be connected to a switchboard. The switchboard allows any two of the stations to be connected to each other.

b. Functions. The switchboard contains circuits and components which permit the following actions:

(1) The calling telephone station is able to signal the switchboard operator.
(2) The switchboard operator can talk and listen to the calling telephone station.
(3) The switchboard operator is able to signal a called telephone station.
(4) The switchboard operator can talk and listen to the called telephone station.
(5) The switchboard operator can interconnect telephone stations connected to the switchboard in the same central office or to those in other central offices.
(6) The called or calling telephone station can notify (signal) the switchboard operator on completion of a telephone conversation.